Blockchain and new organizational models for the innovation management in the supply chain

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- Varriale V., Cammarano A., Michelino F., Caputo, M. “Integrating blockchain, RFID and IoT within the supply chain: a cost analysis”, *Journal of Industrial Information Integration*, under review.

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Abstract

Recently, research and entrepreneurs have shifted their attention to new technologies such as blockchain and cryptocurrencies to understand how they can be deployed within their organizations. In particular, the adoption of blockchain is moving towards implementation within supply chains to track and make transparent companies' activities. Blockchain is a decentralized technology that allows data to be recorded on immutable ledgers that are provable by everyone, making it a secure and reliable tool. In addition, the use of smart contracts, Internet of Things and RFID allow optimizing operations management. Moreover, the lack of adoption by managers and the high implementation costs hinder their application.

This thesis provides an overview of blockchain's opportunities and challenges for supply chain management. It investigates how blockchain can be integrated with other technologies following the Industry 4.0 perspective and evaluating its implementation in enabling sustainable practices. To date, there are still few real cases and projects in full operation. Hence, the purpose of this thesis is to assess *ex-ante* the potential benefits that technology can bring to operations management within supply chains in specific areas such as inventory management, logistics and order management. Based on a cheese supply chain, the research compares and measures traditional practices with a scenario in which blockchain technology is included. Specifically, the scenarios measure the impacts on time that blockchain technology can carry out by automating several operations compared to the traditional solution. Consequently, the introduction of a cost analysis will allow understanding and quantifying the advantages and disadvantages that technology carry out to each area and actor. The implications that would derive downstream of these analyses would allow a greater adoption of the technology by entrepreneurs and an in-depth study by researchers to search new solutions and strategies for optimizing supply chains.

General Introduction

In the last five years, Blockchain Technology (BT) has considerably increased its popularity. It is estimated that its market will exceed $ 39 billion by 2025 (Cerley et al., 2019). It is a Distributed Ledger Technology (DLT) which make it possible to store data in a decentralized manner, without a central authority. It became popular in 2008 thanks to Satoshi Nakamoto, who introduced Bitcoin, one of the most popular cryptocurrencies (Nakamoto, 2008). The first evolutionary level of blockchain, or blockchain 1.0, dates to the first applications in the 90s when distributed technologies allow recording the time of a digital transaction to avoid tampering with documents. The second evolutionary level, blockchain 2.0, is based on the introduction of digital payments. Blockchain level 3.0 implements a new type of application: smart contracts, a digital protocol that allows the execution of contract agreements without the involvement of third parties. The fourth evolutionary level, blockchain 4.0, focuses primarily on art, culture, education and government. Finally, the last level (5.0 blockchain) relates to the application in business cases (Etemadi et al., 2021; Gurtu and Johny, 2019; Tandon et al., 2021). Figure 1 shows a timeline of BT evolution.

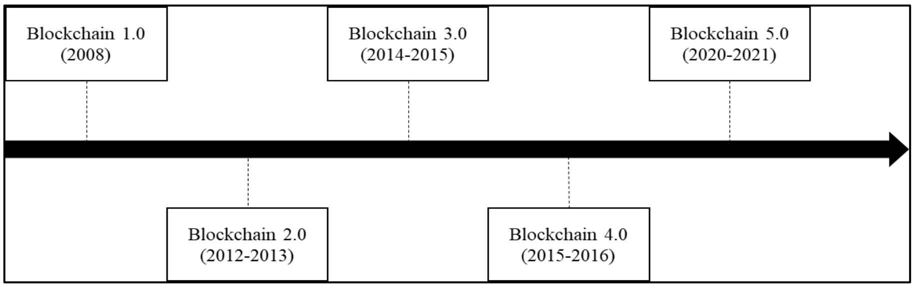


Figure 1. *Timeline of blockchain evolution.*

The huge success of this technology is based on its intrinsic features such as: decentralization, disintermediation, encryption, immutability and tokenization (Gan et al., 2021; Gao et al., 2021; Omar et al., 2021). These elements are fundamental as they allow network participants to interact safely even without knowing each other. These peculiarities have ensured the use of technology mainly in the financial field, i.e. with exchange of financial transactions based on cryptocurrencies (Beinke et al., 2021; Lambert et al., 2021). However, the technology is spreading rapidly in many business areas, for example, in support of supply chain activities (Gökalp et al., 2022; Lechler et al., 2019; Li, Ceong, et al., 2021). In the current scenario, supply chains are plagued by various challenges including market complexity, partners relationships, disruption events, globalization, risk management, digitalization and the achievement of Sustainable Development Goals (Melnyk et al., 2022; Novak et al., 2021). Therefore, the adoption of emerging technologies such as blockchain could solve some of these issues. Several studies have studied the technology in changing the organizational aspects of companies such as the tracking of the counterfeit products and the fraud reduction (Azzi et al., 2019). Furthermore, blockchain has proved its value in enabling the transparency and visibility of transactions exchanged among partners by improving the concept of trust in partnership (Sunny et al., 2020). It can enable better processes and activities management that can be expensive and non-transparent (Ronaghi and Mosakhani, 2021). Traditional centralized information technology infrastructures on which business transactions are performed to establish trust, authentication and payment were not built to handle thousands of transactions in a secure and efficient way (Roeck et al., 2020). Companies need to manage and collect data without involving a centralized intermediary and use transactions as data exchange trace (Dong et al., 2021). By employing decentralized solutions, organizations can acquire data at low cost and have benefits in the value chain (Hastig and Sodhi, 2020).

Today, active or under development blockchain platforms for supply chains use only a few peculiar elements of technology. In some cases, companies may not need the technology to achieve their objectives. Indeed, the stand-alone use of BT within the supply chains does not guarantee the processes and activities optimization since it needs to upload data from external systems (Feng et al., 2020). For this reason, blockchain is increasingly combined with Internet of Things (IoT) and RFID to collect information, for example to monitor the goods traded (Helo and Shamsuzzoha, 2020), or with artificial intelligence and big data to manage inventory (Dong et al., 2021). In addition, smart contracts can be used to increase the degree of automation within operations management. These tools enable greater efficiency for managing traditional operations by carrying out actions upon the occurrence of specific events (Dolgui et al., 2020). However, several challenges interpose for the implementation of these technologies. First, technological challenges such as latency, scalability, throughput, interoperability affect the low adoption of the technology (Kouhizadeh et al., 2021). Moreover, the adoption requires specific skills and competencies for supply chain operations. Often managers are unaware of the potential of the technology or do not want to adopt it without seeing the benefits of the implementations by other actors (Falcone et al., 2021). Furthermore, the implementation of this architecture requires investments in software, hardware and specific skills (Cole et al., 2019).

In the following sections, the mechanism of BT will be provided in order to highlight its strengths from an IT point of view. In particular, the technology architecture and consensus mechanisms will be clarified. Moreover, the public, private and consortium are introduced. The mechanism of a smart contract is described. The research opportunities, the research objective and the methodological design are presented below. Finally, the thesis outline is illustrated.

Blockchain architecture and consensus mechanism

Blockchain is a DLT in which transactions are stored in a secure, permanent and verified way. A transaction is an action that modifies a resource that is in a specific status. The transactions are recorded in encrypted blocks that are linked together. The first block is called “*genesis*” because the other blocks added to the chain are linked to its hash code (Figure 2). Each transaction is saved within a block that is linked to the previous and the next one. The connection between the blocks is done using a hashing algorithm. The task of the hashing algorithm is to associate a distinctive identification code to each block which is then reported in the next block. Adding the blocks to the chain, it is not possible to change them because the modification invalidates not only the block considered but also the entire chain since, when a change is made, the hash code will modify. Each node has a version of the entire blockchain, and the system is continuously updated to ensure that all nodes have an updated copy of the entire chain. Transaction information are logged in the block and the data cannot be corrupted and removed; in this way the information exchange can be traced. Data is available to all the network nodes, and it is held jointly by all nodes (Feng et al., 2020).

Blockchain consists of six infrastructure layers as shown in Table 1.

Table 1. *Blockchain layers.*

Blockchain Layer	Layer elements
Application	Finance; Supply chain; Smart city; Healthcare
Contract	Smart contract; algorithm; script code
Incentive	Issuance mechanism; allocation mechanism
Consensus	Proof of Stake (PoS), Proof of Work (PoW), Proof of Stake Delayed (DPoS).
Network	P2P; communication and verification mechanism.
Data	Data block; hash function; Chain structure; Merkle tree hash; timestamp; encryption.

Starting from the bottom of Table 1 there are:

1) *Data layer*: consists of all the data blocks that compose the blockchain. Each block has a body and a header. The following information are stored in the block header:

- *time stamp*: it provides information on when the block was generated and added to the chain;
- *hash function of the previous block*: it is used to connect the blocks together and to create a chain. This makes it difficult for modifying transactions;
- *nonce*: it is a number that can be used only once and is recorded within the block with the aim of being able to generate a hash code that matches the predefined requirements. The nonce is valid if the hash code generated from this number is below a certain limit. This number is identified by the miners and its modification involves the modification of the hash code of the block;
- *merkle tree function*: it is a transaction storage system that uses a tree structure for the data verification process more efficient.

The following elements are present in the body of the block:

- *hashing function*: used to encode information and assign a code to the block in order to identify and prevent following changes to the block;
- *transactions*: they consist of digital assets that should be verified by the network nodes, approved and, finally, stored in the distributed

ledger. The size of a block has a limited capacity and therefore only a certain number of transactions can be recorded at a time.

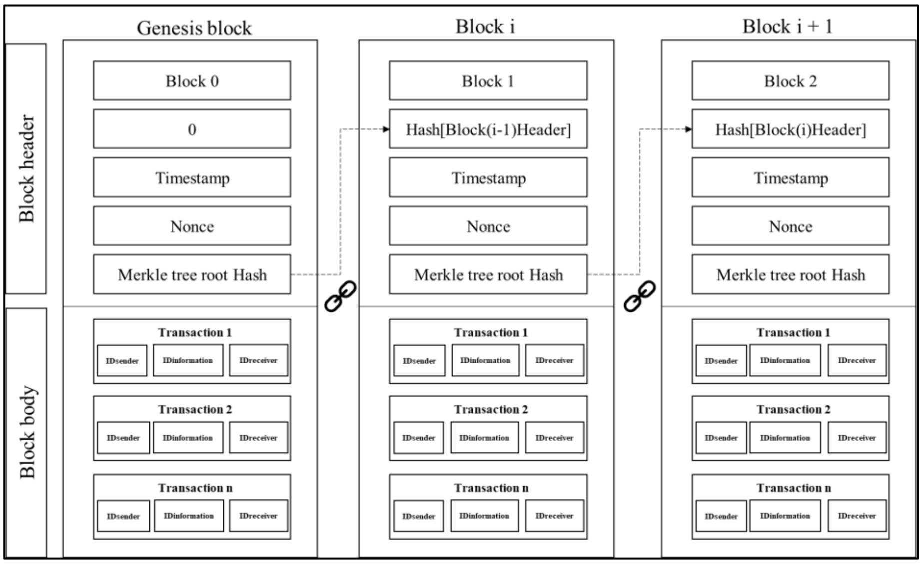


Figure 2. *Blockchain mechanism.*

2) *Network layer*: at this level, information are distributed within the peer-to-peer (P2P) network. The registration of the transactions takes place using a distributed P2P network in which each node of the network has an exact copy of the transactions recorded. Following the registration of a transaction in the system, this is sent to specific nodes selected in charge of carrying out the activities necessary for its validation and, following a positive response, the information is stored in the distributed ledger. The transactions are marked with a private key by the node that creates the transaction. The use of public and private keys enables system security.

3) *Consensus layer*: is the level in which is added the next block to the chain. To reach consensus among different parties, several consensus algorithms can be used, including PoS, PoW and DPoS. Each blockchain chooses the type of algorithm to employ. Consensus algorithms allow defining whether a block can be added to the chain or not. After the user requests, consensus algorithms are used to ensure the correct execution of the transactions and verify compliance with the rules of the protocol.

4) *Incentive layer*: it is a layer where incentives are defined to be used to reward miners for their work. The activities to be carried out in order to mine a block require high computational power, especially in public blockchains. For this reason, it is necessary to define incentives otherwise there would be

no nodes willing to carry out the mining activities, which are the basis of the functioning of blockchain.

5) *Contract layer*: this level includes all scripts, smart contracts and algorithms that execute transactions within the blockchain. Smart contracts can record transactions in blockchain automatically; rules can be implemented on the blockchain, in this way nodes can track business activities and validate contractual agreements (Feng et al., 2020).

6) *Application layer*: at this level all the potential areas of employing blockchain are presented. Among these applications there is also supply chain management (SCM). Other examples of applications are finance, smart cities and healthcare. The application layer represents the user's communication interface with the blockchain (Chen et al., 2018).

Types of blockchains

There are different types of blockchains that can be used for solving various problems. It is possible to classify blockchains according to the presence or absence of a consensus mechanism. The following types of blockchains can be identified:

- *Public blockchain*
- *Private blockchain*
- *Consortium blockchain*

Each of these types has advantages and disadvantages that promote or not its use in a specific field. The choice of the type of blockchain to use depends on the user's needs. Consortium blockchains involve multiple organizations and are used for private applications; they are open to the public but not all data are accessible, the members are known entities which guarantees the transactions' confidentiality, and the consensus protocol is controlled by pre-selected nodes. The public blockchain is the most expensive and slowest solution because each transaction should be verified and synchronized with each node. On the contrary, in the private blockchain the number of nodes involved is less. Due to the high costs and resources consumed, public blockchain is not always feasible while private and consortium blockchains are much more feasible in terms of costs and resources consumed (Khatoon et al., 2019; Kumar, Abhishek, et al., 2020; Kumar, Liu, et al., 2020; Tan and Sundarakani, 2021).

Public blockchain

A public, or permissionless, blockchain is a decentralized system in which any user can decide to join the network (Figure 3). A user can decide to record new transactions in the blockchain and view the transactions already present in the distributed ledger. An example of this type of blockchain is Bitcoin. These platforms are more secure and difficult to tamper with by having a huge number of nodes involved. The reason is based on the fact that to make a modification effective it is necessary to intervene at the same time on a high number of nodes, therefore it is impossible to tamper with. This type of blockchain has low efficiency due to higher response times to consensus requests. Specifically, it takes a long time to receive consensus to add a new block. Since there are many nodes to reach consensus, it is necessary that half of the nodes agree on the transaction correctness. The transaction processing is expensive in terms of time and energy. The transactions are public and accessible to users, however, the user behind a specific transaction remains anonymous. Finally, higher number of nodes involved, lower is the scalability; these features mean that public blockchains are mainly used for mass applications.

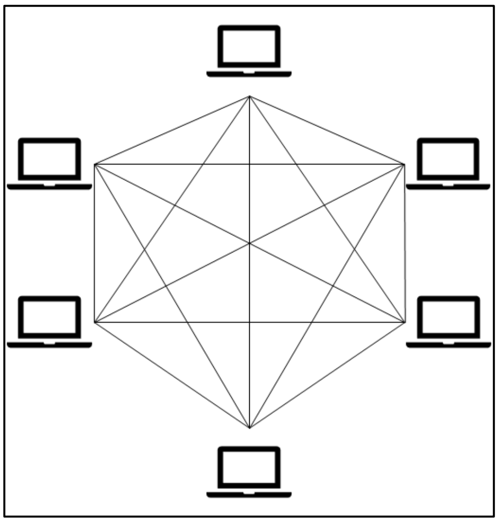


Figure 3. *Public blockchain.*

Private blockchain

In private blockchains, only nodes belonging to a specific organization are admitted to the network (Figure 4). This type of blockchain is used because, being the number of nodes limited, the efficiency is higher than a public blockchain and the time required to obtain consensus is reduced. However, it is easier for a hacker to corrupt the system and modify it as the number of nodes is reduced, and therefore it is necessary to intervene on a lower number of node systems to make the change valid. There are no privacy issues because transactions are viewed only by authorized nodes and scalability increases because the number of nodes involved is less. Access control is entrusted to a single organization that decides who can participate in the network. In particular, there is an entity that is responsible for choosing the nodes that can become part of the system. Private blockchains are part of the permissioned type blockchains because in order to join the network it is necessary to receive an authorization. These platforms allow receiving faster responses to consensus requests because the number of nodes is limited. Furthermore, the identity of all users of blockchain is known and there is no anonymity.

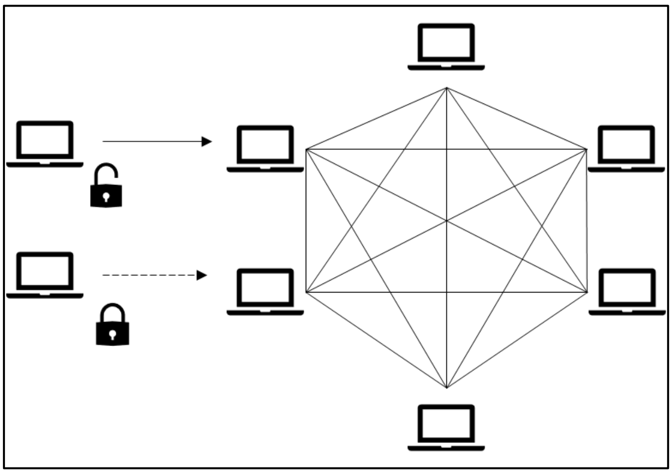


Figure 4. *Private blockchain.*

Consortium blockchain

A consortium blockchain is comparable to a private one, but more than one organization is expected to participate in the network. As in the previous case, the efficiency is high because the number of nodes is still low. However, due to the low number of nodes, the system can be hacked more easily by unauthorized entities. These platforms allow receiving quick responses to consensus requests because the number of nodes is limited, so the verification process is faster. This type of blockchain can be considered as a partially decentralized system, as shown in Figure 5, as only a few selected organizations can be part of it and each of these organizations communicates with its members and with the central authority of the other organizations. As in the case of private blockchains, these are permissioned blockchains because in order to join the network and interact with other participants, it is necessary to receive an authorization. The authorization is provided by a consortium which decides who can participate in the network.

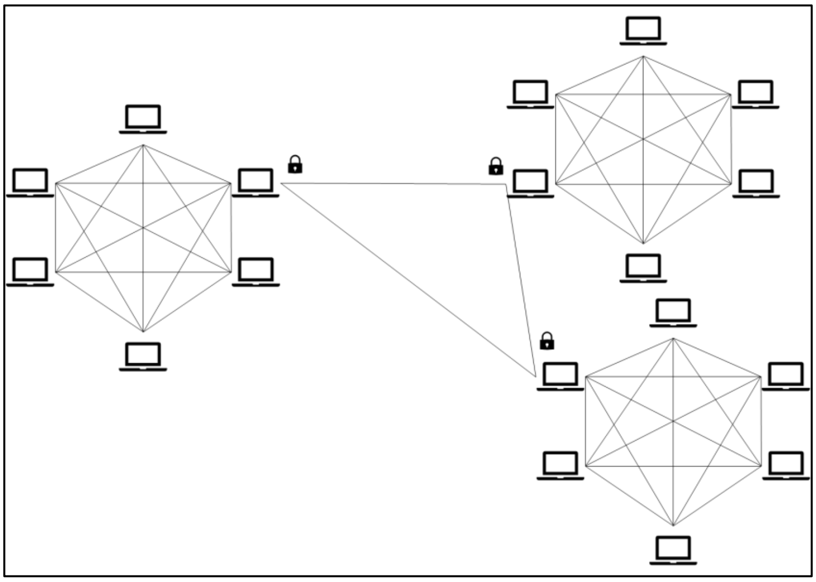


Figure 5. *Consortium blockchain.*

Smart contract

Smart contracts are IT contracts first proposed in 1994. They have become popular today thanks to their interoperability with the blockchain. It is a self-executing code that is saved within the blockchain. The contract includes a series of precise and immutable rules that will be implemented regardless of the two parties. When the conditions included in the contract are matched, a transaction is carried out between the actors involved in the contract. Then, the members of the network agree on the business conditions implemented in the code within the blockchain. Before writing the code and implementing the encryption algorithm, the parties should reach a contractual agreement. Once this is performed, the code is sent to all blockchain nodes for the verification step. The consensus mechanism of the various participants is required for future changes. One of the features of the smart contract is the automatic execution of some activities. When specific conditions occur, the smart contract automatically carries out predefined and agreed actions by the parties involved. The system, based on the rules it receives, decides whether to perform certain actions. Consequently, the smart contract reduces the costs for carrying out the activities. This type of contract involves a significant reduction in human error committed during the operations because it allows the automation. An important advantage is the elimination of intermediaries in defining the contract. Third party intervention is no longer necessary to define contractual terms because, being a blockchain-based system, there is a verification system that does not require trust among the parties involved. This is possible because an automatic verification of compliance with the contractual terms and rules is carried out before the execution of the transaction. The system directly checks whether all the contractual conditions agreed by the actors involved required for the execution of the transactions have been respected. Smart contracts can facilitate payments from suppliers or companies offering services. For example, it is possible to define a smart contract in which, after having delivered certain products, the supplier's payment is performed, then when this condition occurs, payment arises automatically. The use of these contracts allows obtaining information, payments and changes of ownership in real time securely.

Research opportunities

This introductory chapter provides a background on the IT operation of blockchain and clarifies its security features and operating mechanisms that enable its use for SCM. Recently, BT has been recognized as a promising technology in various business processes and activities. Although the literature on blockchain within SCM is still in its infancy, several authors have evaluated its potential impacts in logistics (Pournader et al., 2020), inventory management (Omar et al., 2020), order management (Martinez et al., 2019) and supplier evaluation (Kouhizadeh and Sarkis, 2018). These contributions mainly focused on highlighting what the potential role of technology could be within supply chains, how it could change organizational processes in a conceptual way and how it could be the IT architecture (Venkatesh et al., 2020). Despite the several contributions mentioned above, real success stories of BT are still few considering the international landscape. Often the literature is fragmented into various case studies, pilot projects, interviews with managers and simulations that identify potential benefits, challenges and proposals for future research (Dolgui et al., 2020; Kshetri, 2018; Liu et al., 2020; Xue et al., 2020).

First, several literature reviews present challenges, benefits and directions of future research for BT (Kamilaris et al., 2019; Queiroz et al., 2019; Vu et al., 2021). However, studies are focusing on single aspects of BT. Hence, the research is often fragmented and does not consider the definition of key labels that determine specific characterization of blockchain for SCM. There are studies that focus on specific technological aspects, while other studies focus on supply chain operations. This raises the need to develop a comprehensive classification of the impacts that BT can have on both the IT and the operations management side (Falcone et al., 2021; Kouhizadeh et al., 2021). A comprehensive analysis of the benefits, challenges and future research of blockchain for SCM is needed. Furthermore, research on sustainable supply chains is very focused (Allaoui et al., 2019). Several researchers have investigated the use of blockchain to enable sustainable practices for supply chains (Esmaeilian et al., 2020; Kouhizadeh and Sarkis, 2018). Again, the literature is fragmented as scholars focus on one of the three pillars at time such as environmental, social and economic.

Second, emerging case studies and pilot projects are growing, that integrate blockchain with other cutting-edge technologies. BT is increasingly connected with other technologies to increase the automation, optimization and supply chain efficiency in an Industry 4.0 perspective. However, the literature lacks an overall framework of how and to what extent BT is combined with other technologies and in what contexts of SCM it is employed.

Third, the absence of consolidated case studies does not allow assessing the performance of the technology by an impartial point of view. In fact, there are different simulations present in the literature (Lohmer et al., 2020; Martinez et al., 2019). Some studies simulate IT efficiency in terms of number of transactions, latency, throughput, storage (Tozanlı et al., 2020; Zhu et al., 2021). Other studies try to simulate blockchain in single activities for the operations management such as order or inventory management among few players for SCM (Casino, Dasaklis, et al., 2019; Martinez et al., 2019). This raises the need to develop simulation models that consider multiple actors, technologies, business processes and key performance indicators that allow measuring the potential impacts that the implementation of blockchain connected to other technologies may have in the long term for the operations management. Therefore, a better understanding using key performance indicators for SCM remains essential for evaluating the adoption and the integration of these technologies within companies.

Fourth, considering the integration of such technologies among the various players and on the various activities in the supply chain, few attentions have been paid to the cost challenges. Previous research, through literature review, surveys of managers and business case studies have highlighted how one of the challenges of implementing these technologies is the high implementation costs (Queiroz et al., 2019; Vu et al., 2021; Wamba and Queiroz, 2020). However, literature lacks contributions regarding the implementation costs for each actor and each area of SCM. Given the general enthusiasm for blockchain and the low number of success stories, it is extremely important to understand what barriers interfere with the implementation of these technologies.

Considering what has been discussed in this introductory chapter, understanding the dynamics behind BT on the supply chain is relevant both economically and theoretically. Consequently, the general objective of this thesis is:

General objective: understanding what impacts the use of BT for SCM could achieve and what factors hinder or promote its implementation.

Research objectives and methodological design

Based on general objective and following the research gaps highlighted in the previous section, six research objectives have been defined:

RO1: Identifying the factors that influence the use of BT for SCM

The thesis aims to identify factors that affect supply chain implementation of BT within supply chain operations. Blockchain's features, its benefits, its challenges and future research in SCM were classified in a literature review using specific labels. BT is being considered as a potential tool for building a value-added for SCM.

RO2: Identifying the factors that promote BT for enabling sustainable emerging practices.

The thesis proposes an analysis of the factors that influence the implementation of blockchain to bring out sustainable emerging practices in supply chains following the perspective of triple bottom line. It is necessary to investigate what opportunities this technology could have on sustainable supply chains and which are the critical issues from the sustainability point of view. Therefore, the advantages and disadvantages that the adoption of BT can bring within sustainable supply chains were investigated.

RO3: Identifying which technologies are most complementary with BT to achieve specific impacts.

The third goal of this thesis is to evaluate which technologies are most interconnected with BT to carry out specific impacts in specific business contexts. In literature, several links between blockchain and other technologies in SCM are presented, however in a fragmented way. Therefore, the contribution of this thesis is to provide an overview of all the potential emerging practices that link BT with other technologies present in the current scenario.

RO4: Identifying the impacts that the combination of different technologies such as blockchain, smart contracts, IoT and RFID could have on the order management.

The fourth goal is to compare two simulation scenarios for order management among three actors. Considering that the literature has focused mainly from a conceptual perspective, it is necessary to assess the applicability of these solutions in *ex-ante* business contexts to assess their potential impacts. Two simulation models were implemented considering a traditional scenario and one that employs emerging technologies. Through time-based performance indicators, it was possible to understand what advantages the integration of technologies could have on operations management.

RO5: Identifying impacts that the combination of different technologies and the VMI strategy could have on supply chains with different players and in different areas for SCM.

The fifth goal of the thesis is to investigate the effects that the integration of technologies could have on multiple players and on multiple supply chain areas such as: warehouse, logistics and order management. The literature in this area has often focused on technological performance and less on the operational performance for SCM. Therefore, a study on the different areas of the supply chain considering different actors is necessary. Through various key performance indicators, it was possible to understand the advantages of integrating technologies in terms of time performance and customer satisfaction.

RO6: Identifying the implementation costs that the integration of different technologies can affect SCM.

The sixth goal of the thesis is to evaluate, through Time-Driven Activity Based Costing, what the costs of implementing the integration of technologies in the supply chains are. Based on the previous simulations, the costs of the single technologies for each actor and area were considered. Different procurement policies are analysed to understand when it is economically suitable to integrate different technologies, including blockchain, in the supply chains. The goal is to highlight the economic feasibility of these solutions to understand *ex-ante* the economic impacts within the supply chains.

Thesis outline

The thesis begins with a framework on the main features of blockchain, its benefits, challenges and directions of future research within SCM in *Chapter I*. This chapter shows the sustainable and unsustainable aspects enabled by BT for SCM. In *Chapter II* is shown the linkage between BT and other cutting-edge technologies present in the current scenario. In *Chapter III*, the conceptual models, presented in the literature, are empirically tested using simulation models. In this chapter the main focus is on order management among three actors. In *Chapter IV*, it is presented a comparative simulation model between a traditional solution and one considering the combination of RFID, IoT and blockchain. The analysis is conducted on multiple players and areas of SCM in order to highlight the potential impacts on business performance. *Chapter V* investigates the costs associated with the implementation of different technologies within the supply chains to understand how much and when it is useful to employ these technologies for SCM. In the last chapter, it is summarized and discussed the main findings, the managerial, the theoretical implications, limitations and future research of the thesis.

Chapter I – New organizational changes for sustainable supply chains with blockchain

I.1. Introduction

Supply chains can be viewed as a network of companies, which are linked to each other in different processes that create value to the final consumer in form of products or services. The main purposes of SCM concern costs minimization and customer satisfaction, thus guaranteeing efficiency and effectiveness (Min et al., 2019). To date, these goals are difficult to achieve since the currently challenges are innumerable such as the multiplicity of the actors, geographical distances, delivery times reduced, financial issues management, demand complexity, regulations, sustainability, digitalization and IT security (Christopher and Holweg, 2011; Melnyk et al., 2022; Singh, 2020).

In this chaotic scenario, BT can mediate on some activities. After the huge success in the financial field (Kher et al., 2020), the philosophy behind blockchain has been made available in other areas such as health care (Hasselgren et al., 2020), energy sector (Di Silvestre et al., 2020), public sector (Bavassano et al., 2020) and mainly in supply chains (Habib et al., 2020). Around 2019, the first blockchain case studies for tracking perishable products were starting to be implemented by IBM and Maersk (Kouhizadeh et al., 2020). Specifically, blockchain can be considered a secure technology for exchanging transactions within the internet. Relying on mechanisms such as encryption, distributed nature and data immutability, it allows protecting the sharing information with other stakeholders. These main features guarantee the resilience of the technology to cyber-attacks by malicious actors (Gourisetti et al., 2020). Based on the intrinsic technological features, that make it unique and employable in several fields, the research has indicated this technology as a way for achieving the Sustainable Development Goals (Tsolakis et al., 2021). In particular, blockchain could revolutionize some traditional processes such as monitoring, tracking and tracing, information sharing and waste reduction.

This chapter aims to investigate, through a literature review, the technology features for SCM to understand its potential use in companies, providing an overview of the organizational changes that this technology may introduce in the modern supply chain. The aim is to detect both the benefits and the challenges of BT. The chapter provides a clear overview of the potential of this technology within companies. Moreover, future research are defined for academics and researchers so that they can deepen less explored topics in the academic field. In addition, a further filter is applied to investigate how BT can improve sustainable processes within organizations. The systematic literature review (SLR) was conducted on 74 articles from 2008 to 2020 that discuss how blockchain can change the organizational aspects of supply chains. This chapter investigates the three pillars of economic, social, and environmental sustainability considering BT applied to supply chains. From the analysis of 37 articles, it emerged which are the sustainable emerging practices that BT can enable for sustainable supply chains by defining both sustainable and unsustainable aspects.

This chapter is structured as follows. Section I.2. describes how the SLR was conducted. Section I.3. presents the research benefits, challenges and opportunities. Section I.4. illustrates the sustainable and unsustainable aspects that BT can bring within the supply chains. The chapter closes with discussions and directions for future research.

I.2. A review on blockchain for SCM

In this section, studies related to the use of blockchain for SCM will be outlined. Relevant contributions were collected using the SCOPUS database in which several international publishers such as Elsevier, Emerald, IEEE, Springer, Oxford, Wiley, Taylor and Francis and Sage Journals are present. The search string is based on the use of the keyword "blockchain" in the title, abstract and keywords. The research focused on papers published from

January 2008 (the year of Bitcoin's launch) to April 2020. The research produced 74 contributions regarding the use of blockchain within supply chains. The articles were classified according to the benefits, challenges and future research of technology for SCM. A second filter was applied to identify the articles that discussed sustainability issues. The result of this filter is 37 articles (Table I.1). The papers were also classified according to the triple bottom line, identifying the sustainable and unsustainable aspects of BT for SCM. Figure I.1 shows the steps for the SLR.

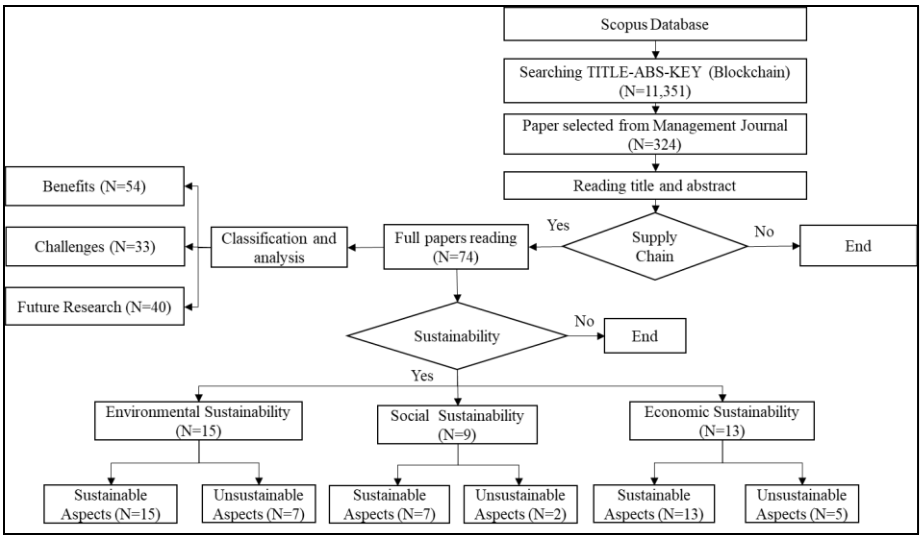


Figure I.1. *Articles' selection and evaluation.*

Table I.1. *Journal wise distribution.*

Journal	**Number of articles**
International Journal of Production Research	11
Sustainability	9
Supply Chain Management: An International Journal	5
Computers & Industrial Engineering	4
International Journal of Production Economics	4
Transportation Research Part E	4
Business Horizons	3
International Journal of Information Management	3
Journal of Cleaner Production	3
Mis Quarterly Executive	3
Resources, Conservation & Recycling	3
Computers in Industry	2

International Journal of Operations & Production Management	2
Journal of Business Logistics	2
Production Planning & Control	2
Trends in Food Science & Technology	2
Applied Sciences	1
Computers and Operations Research	1
IFAC - PapersOnLine	1
International Journal of Physical Distribution & Logistics Management	1
Journal of Purchasing and Supply Management	1
Marine Policy	1
Production and Operations Management	1
Research in Transportation Business & Management	1
Robotics and Computer Integrated Manufacturing	1
Soft Computing	1
Technological Forecasting & Social Change	1
Wine Economics and Policy	1
Total	**74**

I.3. Classification and analysis of blockchain features

In this section, the benefits, challenges and future research will be described. These features will be studied both from the IT and from supply chain performance perspectives. This chapter highlights the strengths and weaknesses of blockchain in greater detail.

I.3.1 Benefits of BT

Blockchain has several important features that incentivize its use in SCM. Table I.2 shows the benefits of BT segmented into *technological benefits for supply chain* and *operational benefits for supply chain*. The percentage considers the number of articles in which the specific benefit was identified on the entire sample of articles analysed.

Starting from the *technological benefits for supply chain*, the use of a decentralized P2P system shared by the whole network allows facing a series of issues typical of a centralized system such as the need to verify the information correctness that is recorded into the distributed ledger. Within the distributed ledger, data are stored in files named blocks and shared with the other nodes of the network (Fosso Wamba et al., 2020). **Decentralization** is a crucial feature because it allows checking whether any information changes have been made (Pereira et al., 2019). In particular, decentralization is used to ensure a redundancy of information since each node of the network has a copy of all the transactions carried out by the parties (Cong and He, 2019).

Although for public blockchains it is not necessary to authenticate to the network with the pair of keys, for private blockchains, **authentication** is considered a key factor in protecting own information (Choi, 2019). The transactions are registered with a cryptographic signature that guarantees their integrity. The encrypted signature is transmitted to the distributed computer network for transaction processing and authentication. Once the transactions are authenticated, it can be recorded to the distributed ledger which finishes the information transfer among the various actors. Each new transaction is linked to those previously stored, offering a complete history (Ehrenberg and King, 2020).

Another benefit of blockchain is linked to the data **immutability** because, once the data have been recorded in a block and the hashing algorithm is executed, the transactions are permanently stored in the distributed ledger (Hughes et al., 2019). The next block is connected to the previous one using the hash code. When the transactions in a block have been modified, the hash code changes and, since all the blocks are interconnected by the hash code, the block and the entire chain are invalidated. The data immutability allows keeping track of all transactions within the distributed ledger and guarantees the transaction integrity (Pereira et al., 2019).

Being blockchain a decentralized system, it limits the cyber-attacks risks by malicious users. In addition, the encryption system, the consensus algorithms and the use of pair keys for private blockchains ensure a high level of IT **security** (Firdaus et al., 2019). Compared to a centralized system vulnerable to hacker attacks and easy to tamper with, the P2P network is decentralized, this creates an information redundancy system that guarantees higher security. Even if a node fails, the system is autonomous due to the P2P system. Blockchain offers a way to address the challenge of protecting and improving security in smart transportation systems and improving the information sharing of supply chain, making SCM more reliable and secure (Kim and Shin, 2019). As a result, the technology could strengthen procedures for detecting fake medicines in global trade (Chang et al., 2020).

The above features, including encryption, block concatenation, and consensus algorithms, make BT **reliable**. Participants have direct control over the information exchanged within the supply chain and, it is important that the information recorded in the distributed ledger are correct in order to properly manage the operations (George et al., 2019).

Regarding the *operational benefits for supply chain*, the **certification** process is fundamental in modern supply chains. Blockchain-based digital certification increases the products' reliability. For example, the luxury goods industry requires a certification system that guarantees quality and compliance with regulations and standards (Choi, 2019). The Everledger case showed how it is possible to certify the transaction history of diamonds by developing a digital identity for each diamond recorded in BT (Kshetri, 2018). Stakeholders such as insurance companies and law enforcement agencies can check on diamonds' provenance. In the case of food production, certifications provide support for a better life cycle of the agri-food product. In this way it is possible to certify the authenticity and integrity of the product, the raw materials and the operations along the supply chain. This hinders counterfeiting and improves the firm's reputation (Pournader et al., 2020; Yadav and Singh, 2020).

In specific conditions, blockchain could automate specific processes. **Automation** is a key driver that allows reducing human errors, costs and speeds up activities and reduces costs (Wang, Singgih, et al., 2019). For example, order management could be carried out through smart contracts that automatically execute actions when certain conditions agreed between the parties are verified (Martinez et al., 2019). To date, to achieve higher automation with blockchain it is necessary to employ other technologies that integrate with the system such as IoT technology (Hasan et al., 2019).

Another crucial feature of blockchain is **disintermediation**. This is an important advantage because such technology can support commercial transactions without intermediaries (Weking et al., 2020). Reducing the number of intermediaries within the supply chain allows minimizing costs and facilitating process management. Blockchain can be used for the disintermediation of traditional intermediaries or financial institutions (Morkunas et al., 2019). Based on a P2P connection, it facilitates partnerships among companies, strengthening and extending supply chains while reducing intermediation costs. It could also reduce the verification steps (Min et al., 2019).

The technology enables **collaboration** among supply chain actors. It is used to provide technological support in external collaboration using data authentication and decentralized operations. The implementation of blockchain solves the information asymmetry issue between internal unit departments and supply chain partners (Pan et al., 2020). At the same time, the consensus mechanism can create an incentive mode among members in a decentralized decision-making system, ensuring that the internal departments can effectively reach consensus on goals (Kouhizadeh et al., 2019). Blockchain could potentially solve supply chain issues such as: faster communication, guaranteeing trust among partners, establishing protected connections, faster payment with lower transaction costs (Bai and Sarkis, 2020). It limits opportunistic and uncertainty behaviour, which determine transaction costs. By reducing costs and allowing for immutable and transparent transactions, the technology can enable more market-oriented supply chain relationships (Tan et al., 2020).

Another feature associated with blockchain is **traceability**. Traceability can be classified into tracking and tracing. The term "tracking" indicates the operation of constantly identifying the position of a specific item. The term refers to the company's ability to keep track of products along the entire supply chain. The tracking process should not be confused with the tracing process which refers to the information collection and analysis acquired by tracking (Ebinger and Omondi, 2020). Blockchain can increase the product and processes traceability in order to record any data: value, time, position, condition and other important information (Chang et al., 2019). In this context, several pilot projects and case studies have arisen such as Walmart, Everledger, Provenance, which have emphasized the importance of blockchain for the traceability process (Kshetri, 2018). For example, the technology could track and monitor medical deliveries that require freezing in their supply chain path in real time. It can support P2P shipment tracking information for suppliers and customers to improve visibility of physical supply chain distribution (Queiroz et al., 2019). Moreover, quality management and forecast accuracy could be improved through blockchain-based traceability (Hastig and Sodhi, 2020).

Another benefit of BT is the **transaction cost** reduction. With the integration of blockchain, the transaction fees are lower than traditional money transfer systems (Wang, Han, et al., 2019). Blockchain can reduce transaction costs, including brokerage needs, and justify trading with micro and small-medium partners (Min et al., 2019). This technology could reduce paperwork and the administrative activities to manage it. Finally, it could reduce potential costs due to human inaccuracy and uncertainty of market trading (Bai and Sarkis, 2020).

Data recorded within BT is available to all network nodes who can access the distributed ledger at any time for the analysis (Astill et al., 2019). The range of **transparency** can be classified into: product transparency such as components monitoring (i.e. the raw materials), process monitoring (i.e. the production stage), product sustainable information (i.e. reusing and recycling) (Bai and Sarkis, 2020). The use of smart contracts without centralized entities (i.e. banks) increases the transactions visibility and consequently the trust between the actors of the network (Pournader et al., 2020). The transparency and visibility of blockchain platform increases the probability of detecting fraud and will increase the counterfeiting costs (Kamble, Gunasekaran and Sharma, 2020).

Blockchain could be useful in **fraud reduction,** for example, curbing illegal business practices, product tampering, illegal trades and criminal activities (Hastig and Sodhi, 2020). The technology could protect digital assets from being stolen or hacked, thus increasing trust between actors of the network (Pournader et al., 2020). It could solve questions by ensuring the terms subscribed in the contractual agreements using smart contracts. Furthermore, blockchain stores and verifies the materials' transformation passing through different supply chain actors (Ivanov et al., 2019).

The above-mentioned features increase the partners **trust** level to the network. Technology can provide excellent communication, control and governance for a company. Firms can employ BT to develop faithful relationships with other actors, ensuring the transparency of their business for customers by avoiding several mistakes along the supply chain (Bai and Sarkis, 2020). Trust is based on encrypted DLTs and the consensus mechanisms which is reached only when all the actors accept the same copy of the DLT (Montecchi et al., 2019). Hence, the concept of trust is one of the major benefits for the technology implementation in supply chains.

Table I.2. *Technological and operational benefits of blockchain for supply chains.*

Area	**Benefits**	**Number of articles**	**%**
Technological Benefits	Decentralization	12	16%
	Authentication	8	11%
	Immutability	10	14%
	Security	22	30%
	Reliability	11	15%
Supply chain Benefits	Certification	9	12%
	Automation	6	8%
	Disintermediation	9	12%
	Partner Collaboration	8	11%
	Tracking and Tracing	24	32%
	Transaction Cost	16	22%
	Transparency and Visibility	25	34%
	Fraud reduction	14	19%
	Trust	21	28%

I.3.2. Challenges of BT

The challenges that blockchain face within the supply chains concern mainly its technological features (Table I.3). To date, there are many blockchain platforms that do not communicate with each other. Moreover, the technology should communicate with other management systems already implemented in the company (Yang, 2019). Therefore, the technology should be developed in order to interact and communicate with other IT systems and ensure **interoperability**. The rise of multiple traceability management systems in the industrial sector can hinder suppliers to the adoption of this technology. Companies that have already invested in CRM, ERP or other IT systems should consider integrating the technology with the current systems (Weking et al., 2020).

One of the major technological problems is the **latency** which is the time that elapses when the block is validated, until it is available in an updated form on the distributed ledger for all the nodes of the network. In the industrial field, latency should be reduced so that supply chain partners can be employed to better manage the information flow and support decisions (Mendling et al., 2018). The use of private blockchains partially solves this issue by improving the number of transactions. The higher number of the nodes, the higher the time required for recording on blockchain. In this direction, algorithms are needed to speed-up block creation and validation (Suhail et al., 2020).

Another challenge is the **data storage** issue. Recording, validating and archiving data in real time is still computationally complex. New data storage models need to be developed to reduce and manage the costs related to data storage. Both in public and private blockchain the blocks have a limited dimension (Saberi et al., 2019). This condition could create problems because there is a limitation on the transaction exchange that it cannot be shared. Blockchain, as Bitcoin, was created primarily to enable high-value transactions in spite of high-volume transactions (Pournader et al., 2020). In the supply chain context, where the transaction volume is high, this incapacity to meet high volumes is worrying.

The size and number of blocks create storage and **scalability** risks for data management. The problem is amplified when data is transmitted after it has been automatically collected by smart sensors. This procedure relies on real-time data transmission which ensures participants making a decision in real time, but this could lead to network congestion (Zhang et al., 2020).

The term **throughput** indicates the ability to create a specific number of transactions per second. The private solutions partially solve the problems related to throughput but, in many situations these are still not enough (Mendling et al., 2018). In particular, the speed of transactions registration and validation degrades by increasing the number of nodes. These features make the technology less agile than other centralized or decentralized systems such as Visa or Mastercard (Pournader et al., 2020).

Different blockchain platforms are proliferating on the market. This creates high competitiveness but, at the same time, the lack of a single **standard** platform for the players involved. The lack of standards has led to a reduction in technology adoption among supply chain members (Jensen et al., 2019). Primarily, the proliferation of paper documents has generated complex security problems (Kittipanya-ngam and Tan, 2020). In addition, documents should increasingly be updated by multiple actors. In some cases, participants are reluctant to accept digital documents because blockchain regulations hinder their use for specific purposes (Chang et al., 2020). Moreover, stakeholders are more concerned about providing sensitive information in common platforms. Therefore, the lack of standard platforms reduce the investment in technological change (Morkunas et al., 2019).

Acceptance of blockchain requires **investments** in hardware and software, which is expensive for companies (Saberi et al., 2019). Blockchain-based manufacturing systems should achieve a significant mass of stakeholders, both buyers and suppliers, in order to create value. In particular, the high expenses will be associated with promoting participation in the network (Schmidt and Wagner, 2019). The future will decide how these developments affect governance costs. Specifically, the development and implementation life cycle is very slow and the professional **skills** and competences have high value (Helo and Hao, 2019). The lack of best practices in implementing this technology in supply chains is a challenge (Mendling et al., 2018). Companies are not interested in adopting technology without first evaluating its benefits. Often, managers are unaware of the potential of this technology (Hastig and Sodhi, 2020).

Blockchain enables the information sharing across supply chain members. Some firms may collect data for a competitive advantage that makes participants unwilling to share important and crucial data (Saberi et al., 2019). Different **regulations** on the use of data could lead to new challenges for sharing data among partners. In the same way, sharing sensitive information among participants, including suppliers, is also a disadvantage of the technology (Hastig and Sodhi, 2020). Data manipulation and **privacy** can be a major concern (Ebinger and Omondi, 2020). Due to the transparency and immutability features, information can be downloaded and viewed by anyone in any place, which will increase the ownership costs of companies with owner information (Kamilaris et al., 2019; Zhao et al., 2019).

Based on the reasons mentioned, the **adoption** of BT within supply chains has slowed down and uncertain in many cases. In fact, the process of adopting BT within industrial and supply chain processes could take years.

Table I.3. *Technological and operational challenges of blockchain for supply chains.*

Area	Challenges	Number of articles	%
Technological Challenges	Interoperability	8	11%
	Latency	8	11%
	Scalability	11	15%
	Storage	5	7%
	Throughput	9	12%
	Standardization	9	12%
Supply Chain Challenges	Implementation Costs	10	14%
	Organization	15	20%
	Governance and Regulations	11	15%
	Privacy	16	22%
	Adoption	17	23%

I.3.3. Future research of BT

The directions for blockchain future research are different (Table I.4). First, it would be interesting to investigate how the **interaction between BT and other emerging technologies** could create value. A promising research agenda could evaluate the effects of BT on SCM when integrated with cloud computing, machine learning, big data analytics, drones and artificial intelligence tools (Min, 2019). Future studies could apply blockchain and edge computing in various manufacturers to evaluate their effects on production (Zhao et al., 2019).

It would be necessary to further assess in which areas are suitable apply the **blockchain security**. For example, technology could significantly improve the implementation of health services, thanks to its potential to manage patient data and prescriptions. Such platforms can address patients to take the proper medicine at the right prescriptions. Several companies have concerns about the privacy issues that arise in establishing a partnership (Tang and Veelenturf, 2019). How can this problem be solved? To ensure that the virtual copy matches the physical copy of the supply chain operations, who should check the records and how often?

The development of **smart contracts** could enable data and financial data among innovators and manufacturers in order to be highly suggested. Combining open innovation theories with blockchain and smart contract in manufacturing systems considering some procurement strategy could be an important research gap in the literature (Rahmanzadeh et al., 2020).

There are concerns about **costs** of implementing BT in SCM. The difference in information and product exchanges could be recognized and considered by scholars, critically questioning the profits to be realized by implementing the technology and evaluating the financial investments required (Cole et al., 2019). The adoption of BT in the supply chain should be encouraged by carrying out assessments on various factors, for example, the network complexity (Tang and Veelenturf, 2019). Will the economic value established by the blockchain implementation outweigh its implementation costs? Will the economic benefit established by operational efficiency of this technology in supply chain outweigh its implementation costs?

Another potential future research direction is to study different **business models** such as how blockchain could change organizational processes depending on the risk of supply chain participants (Choi, 2019). For instance, the presence of a blockchain platform may imply the creation of new sales channels, in this way supply chain members can choose the optimal channel structure and their respective pricing decisions. It will also be interesting to extend the analysis across multiple actors in the supply chain system (Rahmanzadeh et al., 2020). Research can investigate which business processes are most affected by blockchain implementation: sales channels, post-sale service, key activities and partnerships. A further area of investigation could analyse whether a private or public blockchain is the best choice for these elements considered (Morkunas et al., 2019).

Case studies are helpful to investigate the integration of technology within the logistics and transportation (Pournader et al., 2020). As blockchain has been developed for a thrustless environment, the members can have access to data required to extract information in any moments and places (Cole et al., 2019). It would be important to understand how partnership dynamics between supply chain actors can change and how technology could enable and build trust without intermediaries (Saberi et al., 2019). Future studies could conduct a comparative analysis of blockchain barriers across different cultures and business dimensions, such as small and medium-sized enterprises and big companies, to provide strategic insights (Venkatesh et al., 2020).

Another theme is to develop both theoretical and methodological **frameworks**. Research may explore the role blockchain plays in keeping a competitive advantage (Warner and Wäger, 2019). Future studies will be able to assess the effects of a blockchain-based traceability platform from different point of views, such as computational costs, transaction time, storage capacity and the efficiency of supply chains (Zhao et al., 2019). It is necessary to develop new analytical methods for business processes based on BT. Research within this topic will need to investigate how blockchain-based processes can be efficiently employed and distributed. In this context it will need to study how blockchains can enable reorganization of specific processes and collaboration with external stakeholders (Mendling et al., 2018). Researchers will need to consider which features of the blockchain best satisfy the requirements of specific business processes. In this thematic area scholars may study how blockchain could change the company culture (Min et al., 2019).

Barriers regarding the involvement of BT into international trade from both an industrial and governmental point of view should be identified (Chang et al., 2020). Both the entities should jointly recognize the solutions for the interoperability of different IT systems. The integration of blockchain with existing business activities can be improved by identifying the path to follow on this aspect. It would be interesting to investigate how external variables to BT such as competition, industry trends, government actions and the skills of top managers can facilitate its adoption in companies (Min, 2019). One of the priorities for the research of blockchain-based traceability system is to conduct empirical research involving **regulators** or **third-party authority organizations** on different contexts of value chains to assess the system performance. Governments should encourage the digitization of public administration (Zhao et al., 2019). In addition, there is a need to invest in research and innovation, as well as in educational learning, to prove the potential benefits of this technology. Politically, various actions could be done, such as promoting the growth of blockchain-oriented ecosystems in food supply chains (Kamilaris et al., 2019).

In a view of a thrustless environment, some supply chain theories need to be re-shaped considering blockchain. Blockchain, with a distributed transparent systems, can support operational partnership rather than strategic partnership (Saberi et al., 2019). Information visibility, which can include costs, skills and performance measures, can lead organizations to reach short-term relationships. These short-term relationships could improve environmental uncertainty by offering more insight into what other relationships could benefit the organizations considering the operational partnership. BT and smart contracts could significantly help in reducing the overall supply chain coordination, and can be leveraged to improve transparency (Kamble, Gunasekaran, Ghadge, et al., 2020). The research should dig up deeper into the impact of collaboration on business operations, discuss the benefit of **information sharing** and the resources exchange. In this way, it is possible to formulate a better way of operating and improving blockchain implementation measures (Pan et al., 2020).

Researchers could analyse how cryptocurrency can impact on the cash flow and supply chain financial structures. Supply chain partners can now integrate digital currencies into their **payments** (Wang, Singgih, et al., 2019). Research on how blockchains can replenish the middleman and the intermediaries of supply chains could be useful (Wamba and Queiroz, 2020). What is the real cost saving that blockchain technologies allow in supply chain transactions by reducing the intermediaries?

Another trend theme is **sustainability** using digital technologies. Is blockchain a sustainable technology that help companies to create value? BT creates strategies for the data management and sharing platforms, guaranteeing transparency, ownership recognition and data traceability. Future studies should focus on how the technology will support supply chains to increase transparency and automated processes (Kamble, Gunasekaran and Gawankar, 2020). Moreover, research has less investigated on BT for social purposes than economic and environmental aspects. Studies could investigate implementation of BT for the life cycle assessment and design circular economy strategies (Fosso Wamba et al., 2020).

Table I.4. *Future research of BT for supply chains.*

Area	Future Research	Number of articles	%
Future research for technology	Blockchain integration with other technologies	9	12%
	Blockchain security	3	4%
	Smart Contract	2	3%
Future research for supply chain	Adoption	13	18%
	Business Models	4	5%
	Case studies	7	9%
	Frameworks Development	12	16%
	Governance	10	14%
	Information Sharing	6	8%
	Purchasing	8	11%
	Sustainability	8	11%

I.4. BT for sustainable supply chains

In this final section, an in-depth analysis will be provided on BT in improving the triple bottom line for SCM. Starting from the directions of future research, this section is an overview of BT in changing some organizational aspects of sustainable supply chains. This section provides both sustainable and unsustainable aspects by integrating technology within organizations.

I.4.1. Environmental Aspects

Table I.5 presents the environmental aspects that BT could modify within the supply chains. Often, BT is mainly used to improve product life cycle transparency, facilitate circular economies and reduce the carbon footprint of the supply chain through constant monitoring (Hastig and Sodhi, 2020). The transparency of the product's life cycle provides companies with important knowledge to re-evaluate the use of the products and to redesign them that will reduce waste for the entire product life cycle. In recent years, green logistics has an important role. It concerns the planning and scheduling of logistics flow considering new techniques and technologies to reduce environmental impacts (Tan et al., 2020). For example, vehicle routes could be improved to avoid traffic jams and **minimize carbon emissions**. The shipping requirements are stored in the blockchain platform and participants could calculate sustainable solutions (Kouhizadeh and Sarkis, 2018). Delivery companies could use these data to analyse the energy consumption without manual data management to search energy saving solutions (Fu et al., 2018). From an environmental point of view, the possibility to track products can lead to a decrease in rework and returns. This reduces both the consumption of resources and greenhouse gas emissions because the transportation is less used (Saberi et al., 2019). By tracing the carbon footprint of an item, it is easier to define the carbon emissions of each company and define incentives for the most environmentally conscious companies, allowing to appropriately define the taxes that each company should pay and to bargain carbon resources efficiently in the green resource market (Manupati et al., 2020).

Other processes that can be reshaped with the use of blockchain concern recycling programs and **waste management**. In many cases, recycling programmes are not highly regarded by organisations and society (Saberi et al., 2019). Blockchain could be used to encourage society, through token rewards, of saving recyclable materials such as plastic or bottles. Blockchain could offer a shared platform for connecting organizations to trade their waste and recreate value (Esmaeilian et al., 2020). Companies directly can manage waste without intermediaries and improve profit margins. Smart contracts allow waste exchanges by implementing activities based on specific variables such as the waste conditions, their quality and quantity (Kouhizadeh et al., 2019). Waste traceability, especially of toxic and hazardous waste, is essential. It can be performed by sensors and electronic devices that detect the position of the waste and record data on BT. For example, the IBM Food Trust project relies on monitoring the amount of food waste along the supply chain to reduce it. In 2019, IBM participated in a project to encourage the collection of plastic from the oceans: a system was created that allows the plastic waste exchange collected with tokens that can be used to purchase consumer goods via a mobile application (Howson, 2020; Tsolakis et al., 2021).

Blockchain can be useful in eliminating those products or materials that are not highly sustainable (Kouhizadeh et al., 2019). Indeed, by storing data on the toxicity or high energy consumption of these products/services on blockchain, companies could make appropriate decisions. Furthermore, companies could evaluate the **circularity** performance of both suppliers and competitors and take sustainable actions in a concrete and effective manner (Kouhizadeh et al., 2020). The technology helps to identify energy problems by providing products traceability from their origin to assess their energy consumption and guarantee the correct and effective product disposal regulations (Kim and Shin, 2019). Energy-intensive products and materials that do not meet the minimum circularity criteria should be removed and replaced by other green resources. In this case, technology enables and reinforces the most appropriate decisions to be made (Tan et al., 2020). Some transactions and decisions could be automatically performed by smart contracts after collecting data by RFID and IoT technologies (van Hoek, 2019).

Data analysis with blockchain is the key to ensuring future food security, ecological sustainability and **conservation of resources**. For example, transactions could be recorded that store water conservation information, ensure soil and plant health, and improve environmental management (Sharma et al., 2020). BT could be helpful in data storage related to the use of pesticides and other dangerous elements. Some authors have studied applications that included blockchain, big data and the IoT to connect different energy sources and different manufacturers and users (Kamble, Gunasekaran and Gawankar, 2020). By employing smart sensors integrated with blockchain it is possible to have reliable data on energy consumption. The analysis of these data could lead to the identification of solutions for minimizing energy consumption by reducing environmental pollution (Kouhizadeh et al., 2019).

Energy consumption is the major concern of using this technology. The high computational costs for PoW consensus system are related to the amount of thousands megawatts of energy needed (Kouhizadeh et al., 2021). In order to keep the security of duplicated copies secure, the technology requires high computational power and resources. The process takes place through the mining which has a negative impact on the environment, as well as the extraction of gold or copper (Kouhizadeh et al., 2019).

Table I.5. *Environmental aspects.*

Environmental Aspects	Description	Number of articles	%
Sustainable	Reduction of carbon emissions	6	8%
	Waste Management	4	5%
	Circular Economy	3	4%
	Conservation of resources	2	3%
Unsustainable	Energy consumption	6	8%

I.4.2. Economic Aspects

Table I.6 illustrates the economic aspects that BT could modify within the supply chains. Firms operating with blockchain could authenticate data about their supplies efficiently that satisfies environmental and social standards. These information can be provided to consumers, guaranteeing a competitive advantage (Kittipanya-ngam and Tan, 2020). The information shared on the platform offers companies the advantage of supporting their supplier selection and evaluation. In particular, the absence of intermediaries is an important achievement which improves the supplier selection process. Blockchain helps to spread information to different stakeholders involved, collecting data, checking the environmental materials quality, managing time for new product development and coordinating supply chain members. A fundamental aspect to consider for blockchain is the goods trading. Indeed, there may be problems in developing direct green suppliers and subcontractors. These traditionally invisible entities may be the environmentally most dangerous and underperforming supply chain members. The visibility on the downstream of the supply chain could identify potential subcontractors that may require green development. Blockchain has demonstrated significant advantages for supplier development programs and **collaboration**. Blockchain could record the amount of time and costs for a supplier development program (Cole et al., 2019). The type of knowledge exchanged provided to suppliers could be traceable. The information recorded provides the basis for measuring the supplier performances (Bai and Sarkis, 2020). Comparison of performance before and after implementation of a development program can be done on blockchain. Moreover, organizations can ensure to trade with sustainable suppliers using smart contracts (Kouhizadeh and Sarkis, 2018).

Data monitoring and **traceability** are a typical function of supply chain operations to achieve information transparency. The powdered milk scandal in China has shown how tampering with the food supply chain can cause high risk to people (Helo and Hao, 2019). For instance, considering a foodborne disease outbreak, retailers can trace the source of products' contamination on blockchain. IBM and Walmart, in 2016, have developed a blockchain to support the food tracking (Howson, 2020). Walmart has achieved significant improvements in transparency with the introduction of this IT system that combines barcodes and automatic identification technology with blockchain platform (Morkunas et al., 2019). BT records several transactions in which various information such as batch numbers, expiry dates, products origin, and shipping details are available to network participants. Walmart also used this solution to track mango. This project showed that mango took three days for leaving Mexico and arriving in the United States. Previously, these information were unknown to the retailer. The adoption of BT has allowed a reduction in the arrival time of goods, but also an increase in the time it took to purchase the product before it was expired (Astill et al., 2019).

Blockchain can integrate orders fulfillment, distribution, goods payments and communications. The technology could bring several benefits for supply chains issues such as: real-time transmission, guaranteeing trust among participants, and building reliable relationships (Bai and Sarkis, 2020). The real-time transparency based on blockchain guarantees manufacturing companies to have high profits and be sustainable. For instance, manufacturers could effectively reduce the verification costs and prevent distortions of the goods quality through real-time visibility. Companies that use the technology could improve supplier relationships, thereby eliminating trust costs and reducing verification costs. The latter are the costs of checking that suppliers are operating correctly. The mechanism of the technology allows manufacturing companies to eliminate the manager surveillance cost (Ko et al., 2018). Furthermore, paper documents are inefficient and expensive both for the companies that collect information and for the other stakeholders who have to monitor these activities. Specifically, the conservation of paper documentation is the prevailing method considering the previous regulations. These inefficiencies translate into a lack of product and event traceability, a lack of compliance in terms of legal and administrative requirements and a weak control by the personnel (Nikolakis et al., 2018). Blockchain provides more efficient **transaction costs** through a distributed ledger system where different actors within the network can independently verify transactions. Using smart contracts, it is possible to speed up decision-making processes based on shared information. For instance, blockchain and smart contracts could manage payments faster with lower transaction fees (Bai and Sarkis, 2020).

Blockchain could be useful for inventory management, optimizing accounting and business planning processes. It could improve productivity, reduce waste of time on monitoring processes and increase competitiveness within B2B landscape (Lahkani et al., 2020). It could reduce resources and waste consumption, and also make more accurate forecasts for all actors in the network. Effective information sharing can enable collaboration between network actors and build stronger strategical relationships (Kouhizadeh et al., 2019).

In addition, the **implementation and maintenance costs** of BT do not guarantee a fast adoption. It requires both a cost for the entire architecture and for the transactions (Choi and Luo, 2019). The cost for the manager skills should be considered (Kamble et al., 2019). Finally, conflicts of interest may occur among the different members of the network in which an actor can take **opportunistic behaviours** because supply chain members can create economic damage to the entire supply chain (Esmaeilian et al., 2020).

Table I.6. *Economic aspects.*

Economic Aspects	Description	Number of articles	%
Sustainable	Collaboration among participants	6	8%
	Tracking of the products	4	5%
	Costs and transaction times reduction	2	3%
	Enabled planning forecast	1	1%
Unsustainable	Implementation and maintenance costs	4	5%
	Opportunistic behaviours	1	1%

I.4.3. Social Aspects

Table I.7 presents the social aspects of the use of BT in SCM. Opacity in supply chains allows for the exploitation of natural and human resources. Indeed, the value of illegal trade has increased and amounts to billions of dollars annually. Responsible companies should use ethical procedures and behaviour to ensure the sustainability of their supply chains (Hastig and Sodhi, 2020). For example, food products such as coffee and cocoa beans come from developing countries. As supply chain activities are complex and less transparent, the market price of these products tends to be volatile (Nikolakis et al., 2018). To overcome these challenges, there are projects that track coffee by integrating blockchain, cloud computing and artificial intelligence to monitor every stage: harvesting, washing, drying, grinding, exporting, roasting and retailing activities (Tang and Veelenturf, 2019). Farmers could deposit the collected coffee beans into a machine that uses 3D scanners, computer vision and artificial intelligence to define the coffee beans quantity and quality. Then this system will provide a receipt to them and, finally, they could provide fair payments. Another project has been launched in 2017 by the WWF to monitor tuna fishing in the Pacific with blockchain that allows guaranteeing that the fishing activities have been carried out in compliance with workers' rights (Howson, 2020). Specifically, blockchain platform allows workers to anonymously register their working conditions, so that customers can know how workers are treated and choose products made only and exclusively in respect of **human rights** (Ebinger and Omondi, 2020). With this technology it is possible to check the respect of children rights. Many agricultural production activities, for example the activities of the cocoa supply chain in Africa, are entrusted to children. To reduce child labour on cocoa plantations, a smart contract has been implemented that allows checking the age and conditions of children. If the constraints imposed are not respected, farmers do not have the authorization to start agricultural activities which risks blocking the entire cocoa supply chain. In addition to children's rights, blockchain allows monitoring the status of women and gender minorities in supply chain activities to avoid unfair treatment in the workplace. Beyond that, blockchain could reduce bureaucratic effort in drafting paperwork by minimizing costs due to human error (Ehrenberg and King, 2020).

The technology could provide **fair working practices**. For example, immutable product's history can avoid unethical behaviour (Helo and Hao, 2019). Smart contracts can be useful for monitoring and controlling the new sustainability rules (Kouhizadeh et al., 2021). For instance, the performance of truck drivers can be calculated using electronic recording devices. These devices could signal the increase in speed which causes an increase in carbon emissions. Blockchain can incentivize the correct driver's behaviour by providing him with a reward based on correct driving and reduced fuel consumption (Kouhizadeh and Sarkis, 2018). Other social sustainability challenges concern the low transparency of activities, a low controlled regulation, lack of payment monitoring and low safety conditions at work. In some cases, BT could be used to record the working hours of employees and monitor the limits of working hours and the resulting payments. Additionally, physical data such as lighting, humidity and temperature could be tracked at workplaces to monitor workplace safety (Tang and Veelenturf, 2019). **Employee health** data can also be recorded in the blockchain to enable additional guarantees for workers.

However, the advancement of these technologies has led to the reduction of all intermediate jobs and higher **unemployment rates**. The use of BT must provide for a reorganization of the job skills for the new generations.

Table I.7. *Social aspects.*

Social Aspects	Description	Number of articles	%
Sustainable	Ensuring human rights	5	7%
	Ensuring fair practices at work	1	1%
	Ensuring healthy and safety workplace	1	1%
Unsustainable	Increasing the unemployment rate	2	3%

I.5. Discussions

This chapter has offered an overview of the different perspectives of BT by evaluating its benefits, challenges, future research and sustainability aspects. Research on BT is growing rapidly due to its flexible employability in various fields. Thanks to the intrinsic characteristics of blockchain such as decentralization and immutability, blockchain could be considered a trusted third party. For this reason, its application reduces transaction costs and eliminates intermediaries. Specifically, the main technological benefits of the technology concern high security based on specific encryption schemes and the guarantee of having redundant data on multiple nodes to preserve the truth. In the context of SCM, the greatest benefits mainly concern the complete product's traceability, the fraud reduction and the total transaction's visibility. The technological benefits converge in generating **reliability** in the technology, while the benefits on supply chain operations aim to strengthen the concept of **trust** between the players in the network. Figure I.2 highlights the two key concepts that BT promotes.

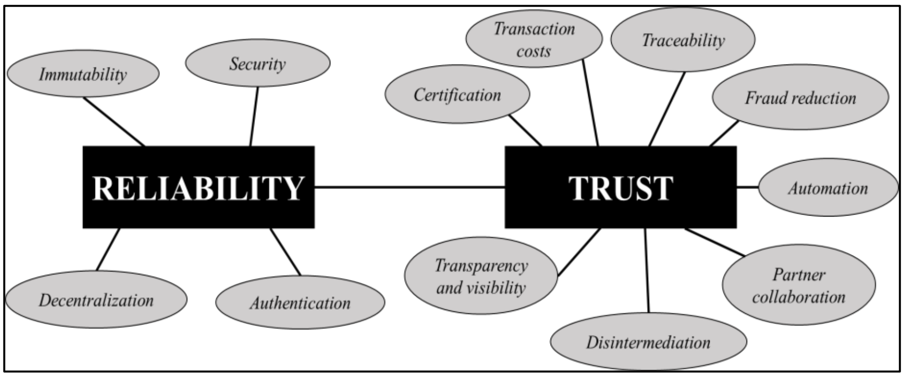


Figure I.2. *Blockchain opportunities for SCM.*

There are several challenges still to be addressed. On the one hand, the technological challenges are based on the management of a high number of transactions and assurance the same technological performances that are available with the current information systems. One of the biggest problems is the lack of platforms standardization which consequently causes issues of interoperability, latency and scalability. The challenges within the supply chains remain implementation costs. The lack of technology knowledge and privacy issues that could create opportunistic behaviour. Finally, the technology has not yet been regulated in several countries. This has raised suspicion in supply chain applications. Overall, the main challenge for supply chains is its large-scale adoption and integration. Figure I.3 highlights the two key concepts for blockchain challenges. On the one hand, technology should achieve a standardization in order to reduce technological challenges. On the other hand, adoption by several companies is necessary to understand the added value for supply chain network.

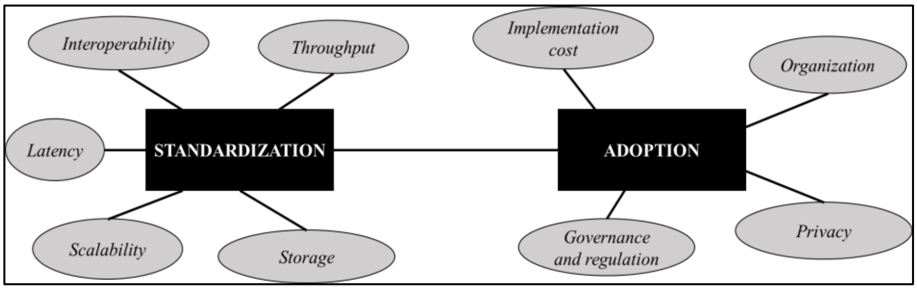


Figure I.3. *Blockchain challenges for SCM.*

The future directions of blockchain can be divided into technological and operational performance for SCM. It would be appropriate to investigate how BT could be combined with other technologies in an Industry 4.0 perspective. Certainly, research will need to further investigate the security principles that emphasise the improvement of resilience against cyber-attacks. Further inspiration for future research concerns the implementation of smart contracts, verifying their effectiveness and computational efficiency. It would be useful to verify the automation degree that could derive from the implementation of these tools in industrial environments. It is necessary to analyse real case studies that could become best practices. Moreover, it would be useful to study what business models the adoption of blockchain could create value. The analysis of some features such as knowledge sharing would be helpful for understanding the potential of the technology's visibility and transparency. Research can be pushed into the framework development and simulations to verify the potential of this technology in a preventive and predictive manner. Finally, the research could consider the role of blockchain in managing sustainable supply chains. Figure I.4 illustrates the future directions of BT for SCM. On the one hand, it is necessary to develop and improve the technological performance of blockchain by integrating it with other technologies. On the other hand, it is necessary to investigate how technology could impact effectively on the companies’ aspects and on the supply chains management.

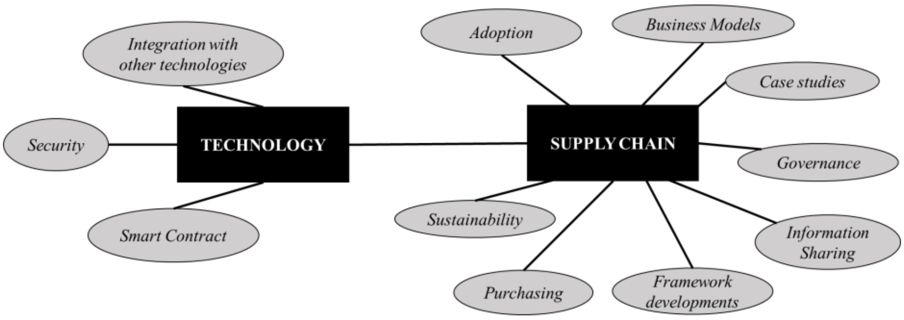


Figure I.4. *The future of BT for SCM.*

In this chapter the issue of sustainable supply chains was presented by adopting BT. The chapter emphasized the importance of BT in supply chains following the triple bottom line approach. Due to its previously mentioned features, the technology guarantees a higher transparency and a reduction of energy consumption. It is possible to track waste and consequently improve circular economy processes. An example is the tracking of waste or carbon emissions on BT. It can enable virtuous processes of social sustainability by tracking working hours in developing countries. Furthermore, it enables scheduling to reduce transaction costs. From a social sustainability side, it guarantees workers' standards by eliminating fraudulent activities such as slavery or child labour. However, technology supports unsustainable aspects. For example, adopting public blockchains is highly energy consuming. The implementation and investment costs are high. There are privacy issues that if not managed properly could facilitate opportunistic behaviour. Finally, automation could increase the average unemployment rate. Empirically defining which aspects prevail for the technology implementation is still difficult to establish. Specifically, how much does the adoption of sustainable practices via blockchain weigh on energy consumption? The adoption of private consortium-based blockchains might not be cost-effective as existing IT systems could be implemented. It is still difficult to determine empirically which aspects are more relevant for the implementation of the technology. In literature, there are several studies that through qualitative assessment try to demonstrate how technology could potentially impact on sustainable supply chains. Indeed, research may study in various directions including the integrated use of different technologies such as sensors, IoT, machine learning techniques, drones and blockchains. This would be useful for studying the combined impacts of the various technologies on sustainable supply chain operations. However, research in this area is still in its infancy. It is necessary to develop simulation models capable of predicting the potential value of the technology on traditional supply chains. In this way, academics, researchers, and practitioners will be able to understand the effective utility of technology in various fields, sectors and activities. The data measurement will allow for a greater ease of analysis for a cost-benefits of the technology. The next step is to investigate and verify if these theories are verified in real case studies. It would be necessary to analyse several case studies and understand the new situations that have developed since the introduction of this technology. Literature on SCM is increasingly pushing companies to adopt BT because it enables new sustainable practices for managing operations. Of course, the use of a private or consortium blockchain and its consensus mechanism allows crucial information to be recorded and managed properly.

This chapter has laid the theoretical foundations needed for the next chapters. Specifically, a framework of the technological features of the technology and its impacts on supply chain operations was presented. A second study was carried out to understand what sustainable impacts' BT can bring if adopted within supply chains. BT can be considered a new way to manage the collaboration among the supply chains members, ensuring the respect of each network participant. Some of these research topics will be further explored in the following sections. For example, *Chapter II* provides the analysis of the combination of BT with other technologies present in the current scenario. *Chapters III* and *IV* explore how BT, integrated with other technologies, can change organizational aspects and improve overall organizational performances. Finally, *Chapter V* will investigate what the implementation costs are for each actor and single area for SCM.

Chapter II – The combination of blockchain with other technologies in supply chain management

II.1. Introduction

Digitization within supply chains has always been an important topic, revolutionizing relationships between partners and optimizing SCM activities (Agnihotri et al., 2022; Yang and Lirn, 2017). As stated in the previous chapters, scientific research has investigated the opportunities of implementing BT in SCM, evaluating its intrinsic characteristics that guarantee its uniqueness and usefulness. Considering the concept of Industry 4.0, based on the interconnection and automation of production systems, blockchain could be a fundamental technology for SCM (Hopkins, 2021).

In this context, many other technologies have an important and consolidated role for the operations management. In literature, several studies investigate the use of different technologies to improve internal and external aspects (Cañas et al., 2021; Szalavetz, 2019). For example, Bag and Pretorius (2022) assessed the challenges and opportunities of the digital revolution, analyzing artificial intelligence and big data, for sustainable production and the circular economy. Ali and Phan (2022) have evaluated warehouse management in a sustainable way with IoT, RFID, blockchain and big data. However, an exponential growth of articles on blockchain and other technologies has emerged in the field of SCM (Ebinger and Omondi, 2020; Hartley and

Sawaya, 2019). Scholars have focused on specific applications where this technology is employed in operations management. However, there are few scientific contributions that analyse BT by integrating it with other technologies present in the current landscape. Therefore, the literature on combining blockchain with other technologies in reshaping supply chain processes is fragmented and limited to a few combinations of technologies.

Specifically, an overview of blockchain implementation opportunities is lacking by combining it with other technologies in SCM considering specific business processes and achieving specific impacts. Through an SLR, the aim of this chapter is to provide a portrait of applications, case studies and simulations that identify how blockchain integrates with other technologies can improve internal and external aspects in specific business processes in SCM. The scientific articles were classified according to the specific technology, the business process and the impact. In particular, 29 different types of technologies classified into 9 main categories were detected. These technologies have been grouped into: *artificial intelligence (AI), computing (COM), digital applications (DIG), geospatial technologies (GEO), immersive environments (IMM), internet of things (IOT), open and crowd-based platforms (OCBP), proximity technologies (PRO)* and *robotics (ROB)*.

This chapter contributes to blockchain literature by showing the state of the art of BT for specific business processes to achieve specific impacts. The analysis provides an insight into technological advances for integrating emerging technologies with blockchain. The analysis evaluates the combination of blockchain and other technologies present in the current scenario in order to achieve a specific business performance. A framework is established for managers and professionals to address the opportunities associated with the combined use of various technologies, including blockchain, in different areas of SCM and its impacts.

The chapter is structured as follows. Section II.2. presents the criteria for selecting the articles. The results include an analysis of where BT is applied for certain business processes. A study is then performed on combining BT with the other nine main technologies. The discussion section will have a focus on the theoretical implications. Practical and managerial implications, limitations and future research will be discussed at the end of the chapter.

II.2. A review of blockchain integration with other technologies for the supply chains

A SLR was conducted since it is a method that summarizes the theoretical advancement of research (Tranfield et al., 2003). It aims to understand what other technologies are combined with blockchain, in which business processes and what impacts are achieved. The research was conducted in Scopus considering international Journals in the business, management and economics area. The search string is used in the title and keyword fields, which considers the identification of technologies relating to blockchain in SCM. The search string is “Blockchain” OR “Cryptocurrencies” OR “NFT” OR “Other distributed ledgers” OR “Smart contracts” AND “Supply chain”.

The first step is to identify, on each article, the practices based on the use of technologies in companies. An "emerging practice" is a new way of implementing a technology within a process to achieve a specific impact. Scopus research provided 530 studies covering a time horizon from January 2019 to July 2022. Specifically, 45 documents were not downloadable. The articles read and analysed are 485. This research selected 119 suitable papers related to the supply chain considering BT as focal technology. The suitable articles that contain the information needed to detect the emerging practices, i.e. in which business process they are applied and what impact they have on the business performances for SCM, are collected. Conceptual papers based, and literature reviews are not considered for this analysis. The classification of emerging practices is performed in a standardized way with specific labels or tags to ensure a rigorous classification of the results. The labels considered are the technology used (i.e. blockchain, artificial intelligence), the business processes and the impacts achieved. The business processes considered concern the activities involving supply chain members (Table II.1).

Table II.1.*Business processes for SCM.*

Upstream processes	**Downstream processes**
Supplier evaluation and selection	Warehouses
Buyer-supplier relationships	Transportation
Order management - purchasing	3PL 4PL Couriers – Outsourcing
Supplier payment	Distributors and wholesalers
Raw materials management	Delivery
Operations planning	Sales and sales channels
Operations control	Customer service
Inventory	Post-sale service

This research analyses the impacts that emerging blockchain-based practices combined with other technologies bring to SCM. Figure II.1 shows the external and internal impacts. The former refers to how technology can impact on factors external to organisations, i.e. customers and other stakeholders. The latter refers to the internal organisational impacts of the supply chain or single companies where standard and traditional internal practices are revolutionised and renewed using innovative technologies.

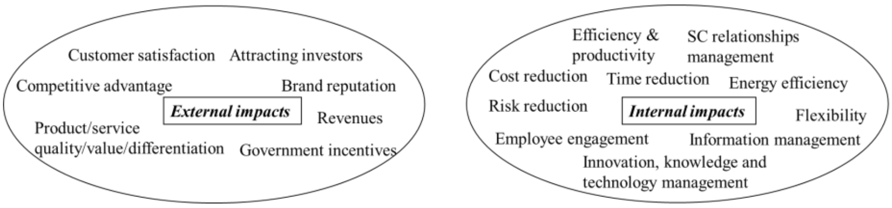


Figure II.1. *External and internal impacts.*

The number of emerging practices of BT in combination with other technologies is 577.

II.3. Classification of blockchain for different areas of SCM

From the sample, 577 practices are associated with the blockchain. Table II.2 illustrates the number of emerging practices in which BT is used depending on the business processes detected. Business processes that have less than 15 emerging practices were excluded from the analysis.

Table II.2. *Distribution of blockchain case study within specific business processes.*

Business process	Activities considered	#BC
Supplier evaluation and selection	Procurement, evaluation, qualification and supplier selection.	**29**
Buyer-supplier relationships	Information sharing, cooperation, coopetition, coordination.	**116**
Order management - purchasing	Order generation, order receipt, quote acceptance, order processing and offers.	**47**
Supplier payment	Bank transfer; cash; credit card; token.	**29**
Operations planning	Planning, scheduling and programming.	**18**
Operations control	Monitoring, Tracking, Tracing.	**80**
Inventory management	Stock levels monitoring.	**19**
Transportation	Freight transport internally.	**57**
3PL 4PL Couriers - Outsourcing	Relationships with third- and fourth-party logistics.	**29**
Distributors and wholesalers	Relationships involving operators such as distributors and wholesalers.	**24**
Delivery	Product delivery.	**22**
Sales and sales channels	Monitoring and controlling the sales channel, creation of a new sales channel.	**25**
Customer service	Customer contacting and requesting.	**19**

Table II.3 illustrates the number of emerging practices classified by blockchain according to their impacts. The impacts that have less than 15 emerging practices were excluded from the analysis.

Table II.3. *Distribution of blockchain case study according to external and internal impacts.*

Impacts	**Description**	**# BC**
External impact		
Customer Satisfaction	Improve customer experience, product customization and the level of service.	**35**
Product/service quality/value/differentiation	Increase the value/quality of the product/service, by ensuring the certification of the product origin or with a product differentiation.	**44**
Internal impact		
Cost reduction	Promote cost reduction by stock reduction.	**62**
Efficiency & productivity	Increasing the machines reliability and production optimization.	**43**
Information management	Improve traceability, monitoring, visibility and transparency of business activities.	**75**
Risk reduction	Reduction of risk at work, fraudulent activities, privacy and security issues.	**58**
Supply chain relationships management	Promote collaboration and cooperation.	**158**
Time reduction	Time to market, design times and production times reduction	**44**

II.3.1. Integration of blockchain with other technologies

Starting from the 577 practices associated with the blockchain: 358 of them are not related to other technologies, the remaining 219 (38%) combine BT with at least one other technology. Moreover, 116 practices reveal the linkage between blockchain and other technologies, in 103 cases more than one technology is combined with the technology.

Table II.4 illustrates the co-occurrences (CO-OC) of blockchain with other technologies. BT is strongly connected to IoT and proximity technologies, respectively. In order to work properly, blockchain needs technologies suitable for data acquisition. The technologies that have less than 15 emerging practices were excluded from the analysis.

Table II.4. *CO-OC of blockchain with the technologies under analysis.*

	BC	AI	COM	DIG	GEO	IMM	IOT	PRO
#	577	30	46	16	37	26	125	95

CO-OC	100%	5.20%	7.97%	2.77%	6.41%	4.51%	21.66%	16.46%

The following Table II.5 shows the taxonomy of the single technologies classified in each category and their description. These technologies have been identified in conjunction with BT.

Table II.5. *Taxonomy of technologies.*

Macro-Technology	Technology	Description
🧠	Classification algorithm	Classification algorithms are supervised learning algorithms that are used to accurately assign test data to specific categories and allow classifying specific issues.
	Deep learning	Deep learning is part of machine learning methods based on artificial neural networks.
	Metaheuristic Algorithm	Metaheuristic algorithms are research procedures designed to find a good solution to an optimization problem that is complex and difficult to solve at optimality.
	Unsupervised learning	Unsupervised learning analyses and groups unlabelled datasets without the supervision of a human. The purpose of these algorithms is to find hidden patterns.
☁	Cloud computing	Cloud computing is the use of services, such as software development platforms and Internet storage services
	Cloud storage	Cloud storage is a technology in which data is stored on remote servers and accessible via the Internet. The storage infrastructure is managed by the cloud storage service provider.
	Fog computing	Fog computing is an infrastructure that stands between edge computing and cloud computing in order to allow more efficient processing, analysis and data storage, thus reducing the

		amount of data that must be sent to the cloud.
	API/webservices	An application programming interface (API) is a set of functions and commands that programmers use to develop software.
	Mobile applications	A mobile application is an application software designed to run on a mobile device.
	Social media & network	Social media are internet platforms that allow users to create content and interact with each other.
	Web applications and platform	A web-based application is a program that is accessed over an internet network connection via HTTP.
	Geographic information systems	A geographic information system (GIS) is a system designed to acquire, analyze and manage geographic data, such as maps, locations and landmarks.
	Geo-spatial intelligence	Geospatial intelligence is information based on an analysis of images and data. It uses images to detect and evaluate human activity and the physical geography of the Earth.
	Global positioning system	GPS is a satellite system that provides the location, speed and time synchronization of an object.
	Digital twin	A digital twin is a digital version of something that exists in the physical world.
	Gamification	Gamification is the use of game design principles to increase customer engagement.
	Internet of Things	IoT refers to the process of connecting physical objects to the Internet.
	Smart sensors	A smart sensor is a device that receives input from the external environment and processes data for future analysis.
	Wireless sensors	The Wireless Sensor Network (WSN) is a group of dedicated and space dispersed sensors to monitor and

		record the physical conditions of the environment.
📶	Near field communication	Near Field Communication (NFC) is a wireless technology that allows a device to receive and interpret data from another device located nearby.
	Qrcode/datamatrix	A quick response code is a type of two-dimensional barcode made up of black square modules on a white background. A Data Matrix is a two-dimensional code consisting of black and white dots arranged in a matrix pattern. The information to be encoded can be text or numeric data.
	RFID	RFID is a technology that uses wireless communication to identify and track the physical location of an object.

In the following sections, the CO-OC of each technology is carried out with grouping practices by business process and impact. The most interesting combinations are those showing higher CO-OC values, as this underscores the need to combine blockchain with other technologies to achieve certain results. These relationships between BT and other technologies are more stable and consolidated in literature and in business practices. Each table reports the count of blockchain practices and the CO-OC for each technology analysed.

Table II.6 shows the linkage between the technologies and the impacts on business performance. Blockchain is mainly linked to the supply chain relationship, information management and cost reduction. As regards relations with other macro technologies, the connection with IoT is predominant for different impact, with CO-OC ranging from 11.36% of product/service/quality/value/differentiation to 38.64% time reduction. This demonstrates that the relationship between blockchain and IoT is widely spread for all business performance improvement purposes for SCM. Blockchain aims to improve transparency in supply chains to track any quality issues. The use of smart contracts allows supply chain participants to add information quickly and securely in order to increase trust when managing operations. RFID, IoT infrastructure and blockchain can be useful for order management. In particular, RFID acquires data associated with the physical status of the goods in the warehouses and into the actor's vehicles. The technology records data securely ensuring the transaction sharing to supply chain members. IoT infrastructure is the communication channel between the

RFID installed to the goods and the DLT. Finally, smart contracts are used to automate order management activities such as purchasing, checking goods in stock and launching the shipment (Sunny et al., 2020).

As for other technologies, artificial intelligence and blockchain allow for better **customer satisfaction**. For example, in fish supply chains the combination of BT with mobile applications and satellite images can improve the transparency and traceability of products by adding further information on fishermen. In this way, investors have more information about it and have more confidence about the information flow (Sengupta et al., 2021). The combined use of blockchain, smart contracts and genetic algorithms allow planning delivery paths, obtaining solutions that reduce costs. These routes, determined by genetic algorithms, allow satisfying more customers with fewer routes, increasing the level of service (Li et al., 2022).

Product/service and **quality/value/differentiation** is supported by IoT and proximity tech, while the **costs** and **time reduction** by computing, geospatial technologies, IoT and proximity tech. To facilitate the activities of logistics companies for real-time status updates, it is possible to combine an online web platform, managed by the cloud that is integrated with RFID, IoT, GPS and blockchain. Customer data, projects and shipments can be uploaded to the platform and the items exchanged can be viewed. IoT and RFID collect data from the external environment and blockchain records data transactions in a secure way (Helo and Shamsuzzoha, 2020).

With regard to internal impacts, **efficiency and productivity** are associated with immersive environments and IoT, while IoT and proximity tech are related to **supply chain relationship management**. A blockchain among farmers, distributors, producers, wholesalers, retailers and consumers could be adopted into a perishable food supply chain during an outbreak to achieve a match between supply and demand that leads reducing food loss and waste. Moreover, blockchain and digital twin can quickly detect contaminated food being recalled (Kayikci et al., 2021).

Technologies such as computing and IoT are associated with **information management**. The use of the IoT, blockchain, RFID, GPS and the cloud could be employed for shipping management systems. RFID can be placed on packages and detect some information about the parts and the place where the item is shipped. GPS devices can track the location of vehicles that transport the item. The IoT infrastructure transmits all the environmental data to the cloud server in real time. Finally, smart contracts could be employed to ensure an automatic and secure payment mechanism between parties such as sender, receiver, vehicle and IoT package. The benefits are in terms of real-time shipment tracking, reduced average shipment processing time and reduced workforce (Baygin et al., 2022).

Risk reduction is associated with IoT and blockchain. The information collected by IoT is recorded in the distributed ledger: the data recorded is permanent and practically impossible to modify, therefore the risk of tampering with and fraudulent actions are reduced (Köhler and Pizzol, 2020).

Table II.6. *Distribution of blockchain practices combined with other technologies by impact.*

Impact								
External								
Customer Satisfaction	**35**	14.29%	5.71%	5.71%	0.00%	8.57%	11.43%	8.57%
Product/service quality/value/differentiation	**44**	0.00%	9.09%	6.82%	0.00%	0.00%	11.36%	13.64%
Internal								
Cost reduction	**62**	6.45%	9.68%	0.00%	12.90%	0.00%	24.19%	16.13%
Efficiency & productivity	**43**	6.98%	9.30%	0.00%	9.30%	16.28%	27.91%	6.98%
Information management	**75**	5.33%	13.33%	2.67%	8.00%	2.67%	26.67%	21.33%
Risk reduction	**58**	3.45%	3.45%	1.72%	0.00%	5.17%	13.79%	6.90%
Supply chain relationships management	**158**	5.06%	6.96%	3.16%	6.33%	5.06%	23.42%	19.62%
Time reduction	**44**	6.82%	15.91%	0.00%	13.64%	4.55%	38.64%	36.36%

The relationships between technologies and business processes are illustrated in Table II.7. Except for inventory management, supplier payment and sales and sales channel, IoT is the prevailing technology combined with blockchain in all business processes. However, another technology that is widely applied in different business processes is proximity tech. In addition, artificial intelligence is combined with blockchain for business processes such as **operations planning, 3PL 4PL Couriers – Outsourcing, delivery** and **customer service**. For example, operators using vehicles for deliveries can share them with other users in the same condition. In this way, the routes can be optimized by a metaheuristic algorithm reducing battery consumption (Xia et al., 2021).

Computing is used in various business processes together with the blockchain such as: **order management - purchasing, operations planning and control, 3PL, 4PL couriers - outsourcing, delivery and sales** and **sales channel**. The information collected by the sensors can be transferred to a cloud server, accessible to all supply chain members. Using smart contracts, an actor can transparently monitor and track the process. After the package is delivered, a smart contract automates the payment (Zheng et al., 2020).

Digital applications are integrated with blockchain mainly for **supplier evaluation and selection**. While immersive environments and the blockchain are used in combination for **supplier evaluation and selection** and **operations planning**. For example, farms can adopt a traceability model and empty packaging disposal for reverse logistics of agrochemical products. Technologies to be adopted include RFID tags, to detect the storage of agrochemical products, and QR codes to monitor and identify agrochemical products along the reverse supply chain. The transactions are recorded (encouraged by gamification through the acquisition of a score) on two blockchains: a private blockchain belonging to the reverse supply chain and a public blockchain where government controls the safe disposal of packaging; then, web pages and API are used for visualizing the product in transit. By recording the transactions and viewing the data along the reverse supply chain, companies will become more transparent, starting from the detection of the agrochemical products to its handling and disposal: the farmer could present them to the State to obtain tax benefits (e.g. green certificates) (Hrouga et al., 2022).

Table II.7. *Distribution of blockchain practices combined with other technologies by business processes.*

Business process	⛓	🧠	☁	📱	📍	🥽	</>	📶
Upstream process								
Supplier evaluation and selection	**29**	0.00%	0.00%	10.34%	13.79%	13.79%	34.48%	34.48%
Buyer-supplier relationships	**116**	3.45%	1.72%	2.59%	8.62%	0.86%	10.34%	14.66%
Order management - purchasing	**47**	6.38%	14.89%	2.13%	0.00%	2.13%	27.66%	25.53%
Supplier payment	**29**	3.45%	0.00%	0.00%	6.90%	3.45%	0.00%	0.00%
Operations planning	**18**	16.67%	27.78%	5.56%	0.00%	11.11%	11.11%	5.56%
Operations control	**80**	1.25%	12.50%	3.75%	6.25%	6.25%	40.00%	16.25%
Inventory management	**19**	5.26%	0.00%	0.00%	0.00%	5.26%	5.26%	0.00%
Downstream process								
Transportation 3PL 4PL	**57**	5.26%	5.26%	1.75%	5.26%	1.75%	17.54%	10.53%
Couriers - Outsourcing	**29**	10.34%	20.69%	0.00%	17.24%	0.00%	34.48%	48.28%
Distributors and wholesalers	**24**	0.00%	0.00%	0.00%	4.17%	0.00%	29.17%	16.67%

Delivery	**22**	27.27%	40.91%	0.00%	31.82%	0.00%	40.91%	40.91%
Sales and sales channels	**25**	8.00%	12.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Customer service	**19**	15.79%	5.26%	5.26%	0.00%	0.00%	10.53%	10.53%

II.3.2. Blockchain with other technologies in specific business processes to achieve specific impacts

This section reports the analysis of emerging practices considering the relationships between the combination of technologies with blockchain in specific business processes to achieve certain impacts. Figure II.2 shows a framework where impacts are displayed on rows and business processes on columns. The combination of the most frequent technologies with blockchain is shown at the intersection of business processes and impacts. A filter has been applied where there are only technologies that have a percentage of emerging practices in combination with blockchain greater than 20% for the specific business process and impact. To gain further insights, external and internal impacts were separated and distinct. For the purposes of this research, business processes such as raw material management, supplier payment, inventory management, reverse logistics, post-sale service and warehouse have been excluded as emerging practices where multiple technologies are combined are less than 20%.

Starting from *upstream processes*, the technologies most combined with BT are immersive environments, geospatial technologies and the IoT for **supplier evaluation and selection**. For example, blockchain in the construction supply chain can ensure data validity. This helps for the selection and evaluation of suppliers (e.g. selecting suppliers with good sustainable performance). Smart contracts and blockchain allow actors to establish digital rules to define the required performance criteria as a condition for imposing rewards or punishments. GIS allows actors to collect logistical data, including delivery schedules, while blockchain makes this data tamper-proof and traceable (Yoon and Pishdad-Bozorgi, 2022). For **buyer-supplier relationships**, proximity technologies are associated, as well as IoT. BT and smart contracts could be used in the aviation industry to create a platform for recording and sharing spare parts tracking data. This system enables reliable and better-quality data sharing between each organization, improving data visibility and information security and reducing information asymmetry within the aircraft component supply chain. In particular, traceability can take place using the IoT with RFID tags to simplify processes and increase efficiency throughout the supply chain (Ho et al., 2021). Similarly, the **order management - purchasing** combines BT with computing, IoT and proximity technologies to achieve specific impacts. For example, smart sensors could automate the orders replenishment for products and automate reordering, in order to be ahead of the times (Saurabh and Dey, 2021). Blockchain integrated with GIS systems enables emerging purchasing practices. Furthermore, it could be used to increase farmers' revenues thanks to the traceability and transparency of the product and the reduction of intermediaries. GIS systems guarantee the origin of the product and could generate the best market prices (Sharma, 2021). Different **operations planning** activities are associated with different data management technologies such as IoT and computing. A blockchain platform collects, processes, communicates and exploits information on the product life cycle. The information is communicated via IoT and blockchain. In this system, each component could be traced through unique QR codes, thus obtaining an identification associated with mobile apps that are developed to guarantee the product traceability in each moment to improve management efficiency, reduce management costs and promote synergy between the parties by limiting the information loss (Li, Chen, et al., 2021). Various technologies are applied in **operations control** by combining BT to achieve different impacts. For example, Blockchain-based Decentralized Applications (DApps) could be employed for secure management of Industry 4.0 assets using digital twin. Security and confidentiality are guaranteed through access control and data encryption. The owner of a digital twin has complete visibility of the product lifecycle and involvement of other actors (Putz et al., 2021). For *downstream processes*, different technologies contribute to the combined use of blockchain in different business processes, achieving different impacts. The same technologies are used for **transportation** and **delivery** as the purpose of these business processes is very similar. BT is used as an information sharing system that employs RFID devices to trace the journey of valuable products along the supply chain and trace their origin to ensure quality and authenticity (Sunny et al., 2020). Applying smart contracts could help delivery companies such as **3PL and 4PL** for achieving a secure, transparent and real-time information exchange, avoiding intermediaries. This translates into a cost and time reduction for them. RFID and the IoT provide a tracking system on every event throughout the supply chain using blockchain to record these transactions. The use of cloud storage is required to collect data in a centralized server and share them on demand to all involved actors (Helo and Shamsuzzoha, 2020). IoT and smart sensors connected to blockchain implemented in actors such as **distributors and wholesalers,** provide transparency to agri-food distribution. Information on temperature, humidity, quality, packaging during the storage process is recorded and cannot be changed (Menon and Jain, 2021). Despite being a new technology, blockchain has been applied as a method for ensuring transparency in the trade of food; transparency reduces counterfeiting problems and improves **customer service**. By integrating BT with QR codes, consumers could control their food from raw material to finished product (Dehghani et al., 2021).

Business process Impacts	Supplier evaluation and selection	Buyer-supplier relationships	Order management - purchasing	Operations planning	Operations control
Customer satisfaction	IMM				
Product/service quality/value/differentiation		IOT; PRO	COM	IOT	IOT
Costs reduction	GEO	IOT; PRO	IOT		IOT; PRO
Efficiency & productivity	IMM		IOT	IOT	IOT
Information management			COM; IOT; PRO	COM; IOT	COM; IOT
Risk reduction		IOT; PRO		IOT	IMM; IOT
Supply chain relationships management	IOT	IOT; PRO	IOT	IOT	IOT; PRO
Time reduction	GEO		PRO		

Business process Impacts	Transportation	3PL 4PL Couriers - Outsourcing	Distributors and wholesalers	Delivery	Customer service
Customer satisfaction	IOT			AI; IOT	AI; IOT; PRO
Product/service quality/value/differentiation	IOT; PRO		IOT; PRO		IOT; PRO
Costs reduction	IOT; PRO	IOT; PRO	PRO	IOT; PRO	IOT; PRO
Efficiency & productivity	IOT			IOT; PRO	IOT
Information management	IOT; PRO	COM; IOT; PRO	IOT; PRO	COM; IOT;	
Risk reduction			IOT		
Supply chain relationships management	IOT; PRO	IOT; PRO	IOT; PRO	IOT; PRO	IOT; PRO
Time reduction	IOT	GEO; IOT; PRO	IOT; PRO	COM; GEO; IOT; PRO	

Figure II.2. *Analysis of blockchain combined with other technologies for specific business processes and impacts for supply chain.*

II.4. Theoretical and managerial implications

This chapter evaluates case studies and simulations present in the scientific literature on the integration of BT with other technologies for SCM. The sample suggests how BT could be combined with other technologies to affect SCM and performance. A sample of 577 practices implementing blockchain is considered. The results underline that around 38% of blockchain practices report at least one other technology, proving the role of blockchain of not being a "stand-alone" technology, but highly combined technology. Results recommend what emerging practices could support the development of future best practices, combining blockchain with different other technologies. In terms of theoretical contribution, this chapter aims to standardize scientific articles to outline an overview on the combination of BT with various technologies to bring out the most successful opportunities in supply chains.

Starting from these results, the integration of blockchain with other technologies produces more internal impacts than those of the market. For external impacts, all technologies are present except digital applications and geospatial tech. The combination of BT with IoT and proximity technologies positively influence the product/service quality/value/differentiation impact. The collection of information from the origin to the final consumer and their registration on the blockchain platform in a safe and reliable way allows improving consumer confidence in the products purchased. The visibility and transparency of the products monitored on different processes guarantees product differentiation. This impact is closely linked to customer satisfaction. In fact, the visibility of various information of product status makes the consumer more aware of what is buying. Finally, machine learning techniques could improve the end customer's experience in purchasing products through cryptocurrencies.

For internal impacts, all technologies are present except artificial intelligence and digital applications. The technologies most combined with blockchain are those that allow automatic data collection through sensors and geospatial devices. These technologies reduce the time dedicated to data collection and, above all, blockchain allows a secure, distributed and shared saving between the actors belonging to the supply chain. Cloud computing and cloud storage are increasingly used in these cases because they improve the blockchain performance in terms of storage performance and recording information. The impacts of information management and supply chain relationships are closely related. Therefore, the same technologies such as computing, geospatial technologies, IoT and proximity technologies are used in the various business processes. These technologies improve the transparency of the supply chain and monitor the status of the product and the process, ensuring shared information between all the players. This enables a strengthening of supply chain partnerships. For instance, the IoT improves the efficiency and productivity of upstream processes and downstream processes. The impact of risk reduction is mainly achieved in business processes in which there is a direct relationship with customers or suppliers, such as buyer-supplier relationship, operations planning, operations control and distributors and wholesaler. The technologies combined are proximity technologies, IoT and immersive environments. They allow making appropriate forecasts, reduce the risks associated with counterfeiting products and identify unethical practices in waste management.

The proposed framework could support researchers and practitioners in addressing current and future research aimed at addressing the challenges that will change supply chain processes with BT and its integration with other technologies. With this framework, it will be possible to discuss how these problems could be solved by combining blockchain with other technologies, focusing on the emerging practices most suggested by scholars. In terms of managerial and practical implications, the framework will be useful to identify practices employing BT with other technologies and their application contexts to consider their implementation for addressing new management challenges. Managers could rely on this framework to find out which other technologies are most employed in combination with blockchain in order to implement them within a specific process depending on the desired result.

The limitation of this research is that the grey literature was not considered. Moreover, only the combination of blockchain and another technology is considered at a time. Therefore, the combined effect of different technologies was not detected. It is possible that researchers have not yet considered some combination opportunities as a result of the practices collected from the scientific literature. Future developments of this research could be aimed at evaluating the evolution over time of emerging practices based on the combination of BT with others in SCM. Additionally, other research databases outside the scientific literature could be used to further understand the linkage of blockchain with other cutting-edge technologies for SCM.

Chapter III – Blockchain, IoT and RFID for Sustainable Supply Chains: a focus on the order management

III.1. Introduction

Recently, research in SCM has been strongly focusing on two key themes: sustainability and technology management for supply chain operations (Remeňová et al., 2020). The issue of sustainability can be considered from different perspectives, in environmental terms for the carbon emission reduction regarding the supply chain operations, in social terms for information transparency among the supply chain actors and in economic terms to safeguard the huge costs due to the market complexity, globalization and companies competition (Larson, 2021).

To date, managing emerging technologies is a critical step for companies to achieve competitive advantage in supply chains. Technologies such as blockchain could change various internal aspects and business models by ensuring greater transparency for the information exchanged (Benias and Markopoulos, 2017). Data for a company is one of the most valuable things and managing them correctly allows having several external and internal advantages. On the external side, information sharing makes consumers more aware of the products purchased and improves the relationship with the company. On the internal side, the information exchange among partners and the complete product traceability allows greater transparency of the ethical practices of each network participant.

Certainly, blockchain, as seen previously, can enable several sustainable practices. However, in the absence of other technologies that collect and store data into the distributed ledger, the technology alone does not allow adequate efficiency for supply chain operations. For traceability and transparency systems, the research has widely analysed detection systems such as GPS, RFID and IoT architectures (Bouzembrak et al., 2019; Chanchaichujit et al., 2020). They allow product monitoring by recording various information such as: date, locations, product features, product conditions. These systems suffer problems related to IT security, interoperability between different technologies and finally the privacy associated with the information sharing in the supply chain. Considering these conditions, blockchain could be considered the linkage between different technologies as it allows the secure information recording within the distributed ledger for supply chain members (Matharu et al., 2014). In addition, other tools such as smart contracts could be taken into account to improve the automation of operations in SCM.

The study on the efficacy related to the integration of various technologies including blockchain is still in its infancy. Many contributions are theoretical and conceptual, some investigate specific case studies and interviews. Scholars often focus their attention on the single technology and not on integration with other technologies. Research has focused more on technological performance of BT such as transaction speeds, reducing latency times and improving throughput (Chanson et al., 2019; Kwak et al., 2020). However, there are few studies that evaluate the integration of technologies for SCM. In particular, there are few quantitative studies that measure the importance of BT in streamlining SCM. This chapter aims to fill the gap in the literature on the evaluation of operations management within supply chains.

Specifically, the purpose of this chapter is to compare two scenarios, one traditional (as-is) and one with the integration of emerging technologies (to-be), among three actors for order management. Simulation will be used because this research methodology allows comparing and analysing two scenarios. The chapter aims to measure the time performance that the integration of these technologies could bring to order management for the evaluation of non-compliant products.

The chapter is structured as follows. Section III.2. presents the two simulation scenarios. Section III.3. shows the results, while Section III.4. reports the discussions detailing the managerial implications and sustainability aspects by clarifying the limitations and defining ideas for future research.

III.2. A simulation on order management

As research on supply chain operations adopting emerging technologies, including blockchain, is still in its infancy, a simulation-based research method has been chosen. To date, real cases that integrate different technologies to improve efficiency, transparency and traceability are still few. The simulation study is a powerful tool to identify in an exploratory way the development of new theories (Ketokivi and Choi, 2014). The results could predict system performance. Without a real model, simulation provides numerical and detailed key performance indicators (Carson, 2004). The discrete event simulation is based Anylogic 7.0.2 software. It is a software that provides a detailed analysis of all steps, is easy to programme and is reliable and accurate. Table III.1 summarizes the studies conducted on supply chain operations considering BT. In addition, for each study the unit department in which the research was carried out is identified, such as logistics, production, order management and inventory. In general, the research focuses on the transaction speed and transaction costs of BT, however, less is discussed on performance for SCM. This chapter aims to test and analyse what research has promoted.

Table III.1. *Literature on simulation studies using BT for SCM.*

Authors	**Technologies**	**Unit department**	**Area**	**Software**	**Technological Performance**					**Operations Performance**				
					Smart contract	No. of Transactions	Computational cost	Speed	Transaction costs	Time performance	Costs	Stock performance	Demand volatility	Carbon tax
(Dasaklis and Casino, 2019)	RFID, IoT,	Inventory management	Inventory strategy	Ethereum	✓									
(Omar et al., 2020)		Inventory management	Inventory strategy	Ethereum	✓			✓	✓					
(Helo and Shamsuzzoha, 2020)	RFID, IoT	Logistics	Shipping, tracking & tracing	Ethereum	✓									
(Yoon et al., 2020)	None	Logistics	International trades	No declared		✓							✓	
(Longo et al., 2019)	None	Inventory management	Information sharing	Unicalcoin and Java			✓	✓	✓		✓			
(Hasan et al., 2019)	IoT, RFID	Logistics	Shipping	Ethereum	✓									
(Casino, Kanakaris, et al., 2019)(Tozanli et al., 2020)	IoT, RFID	No specific area	Tracking & Tracing	Ethereum	✓									
(Martinez et al., 2019)	None	Order management	System architecture & performance	Simul8						✓				
(Manupati et al., 2020)	None	Inventory management	Shipping and market demand	Matlab					✓		✓		✓	✓
(Lohmer et al., 2020)	None	No specific area	Risk management	AnyLogic 8.5.0.						✓		✓	✓	

(Dolgui et al., 2020)	None	Logistics	System architecture & performance	Hyperledger Fabric	✓					
(Tozanli et al., 2020a)	None	Production	System architecture & performance	No declared						✓
(Alonso et al., 2020)	Edge Computing, RFID, IoT, QR Code	Production	System architecture & performance	No declared				✓		
(Sund et al., 2020)	None	Logistics	Shipping	Quorum	✓	✓		✓		
(Shahid et al., 2020)	None	No specific area	Tracking & Tracing	Ganache and Metamask	✓	✓			✓	
(Bai et al. 2021)	None	Production	Tracking	Phyton 3.5		✓				
(Tozanlı et al., 2020b)	RFID, IoT	Waste management	Disassembly-to-order	Arena v15.1						✓

Two scenarios were designed and developed. The as-is scenario considers traditional order management without the emerging technologies; the to-be scenario considers order management employing the integration of RFID, IoT, BT and smart contract. To test the research, a simulation study based on three players was considered: a dairy farm, a carrier and a final retailer.

The product considered for this simulation is an Italian aged cheese wheel. It is subjected to high certification standards. Specifically, the choice of Parmigiano Reggiano is based on the ease of finding data on the production and distribution of the product. One of the main reasons why this case study was chosen is that it is an agri-food product of Italian excellence, very often exported and subject to counterfeiting. BT could hinder fraud and opportunistic behaviour of other companies and guarantee the customer's expectation of product quality. This chapter focuses on a single supply chain process, which is order management. In particular, only order management steps will be simulated as it has been found in the literature that blockchain technology affects information management, supply chain relations and partner collaboration. Therefore, this chapter aims to provide a background of how technology can affect a specific supply chain process. The activities are: order generation by the retailer, order receipt, order processing and fulfillment by the dairy farm, product shipping by the carrier and final verification by the retailer. The comparison between the two scenarios includes these activities to have a reliable representation of the technology's impacts. Secondary data were used for the simulation design: statistical reports (ISTAT, 2022), consortium reports (Parmigiano Reggiano, 2022) and scientific articles presented in Table III.1. Figure III.1 presents the design phases of the simulation study.

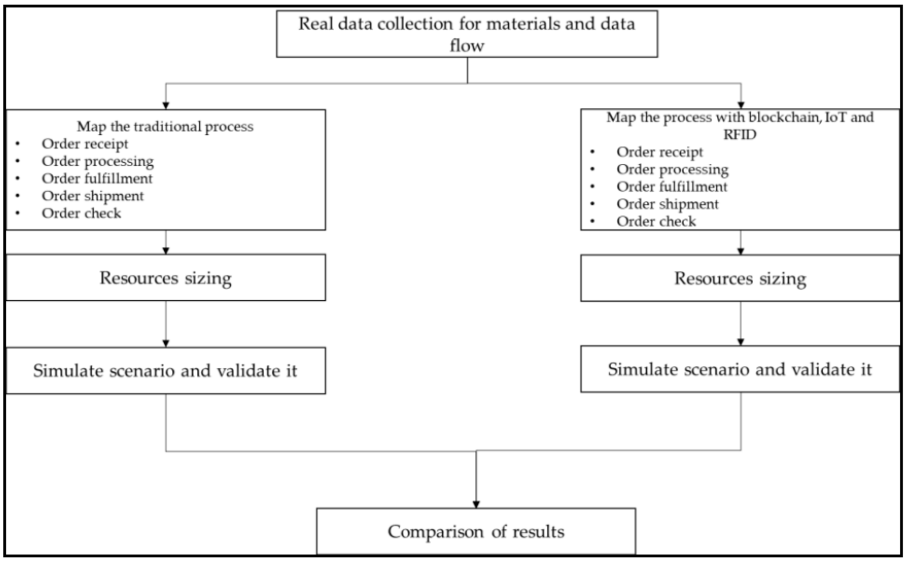


Figure III.1. *Simulation design steps.*

The assumptions considered for the implemented scenarios are the dairy farm warehouse with infinite capacity. This assumption is reasonable as the quantity of product traded is relative to a single actor and they are not so high as to generate stock-outs. The interarrival order from the retailer is 3 days at the dairy farm. Four different products are associated with each retailer's order. The order management unit department works for eight hours for five days. Orders are managed with a FIFO logic recommended for food. The duration of the simulation covers 5 years to understand the long-term impacts of the technology's integration. Non-compliant products are products that do not comply with the standard requirements. For example, a product is not compliant if it has been subjected to a temperature change that has damaged its condition, or the seal opening that compromised the product integrity, wrong documentation or that the carrier does not arrive correctly at destination. The service level considered for both scenarios is 96%, a probability of occurrence of 1% was considered for each disturbance event. Table III.2 shows the parameters considered for this simulation. The two scenarios will be described in detail below.

Table III.2. *Parameters considered in the simulation models.*

Parameters	Description
Runtime	5 years without a transitory phase.
Input	Time for the dairy farm's order management department; Checking time; Time for managing for non-compliant product
Output	Time for perfect orders; Time for non-perfect orders; Average time savings
Number of runs	3,500 replications for each model

III.2.1. As-is scenario

The order exchange between the dairy farm and the retailer takes place via phone calls, email and the use of Excel. The low standardization of the operations generates inefficiencies and high times for order management. Considering the manual activities required for the orders, response and processing times tend to be high. The retailer generates the order, then the dairy farm receives and approves it. The order management unit checks the products availability and then organizes the shipment. The operations considered concerns, the time of order receipt, acceptance, products verification and goods preparation. Once the goods have been prepared, they are picked and placed in an area used for the carrier arrival. The carrier loads the packages and has the task of transporting them to the final retailer.

Finally, the quality control of the cheese wheels is carried out by a retailer's employee. The employee checks the products quality arrived at the destination. During this activity, four events may arise such as the product is not compliant due to temperature variation, the seal opening, the goods are not arrived at their destination or wrong documentation. After the verification step, if there are non-compliant orders, the after-sales process of product returning and reporting the problem to the system is activated. This activity involves reporting errors through e-mail exchanges, phone calls and faxes. Figure III.2 shows the activities for each of the three actors for the as-is scenario.

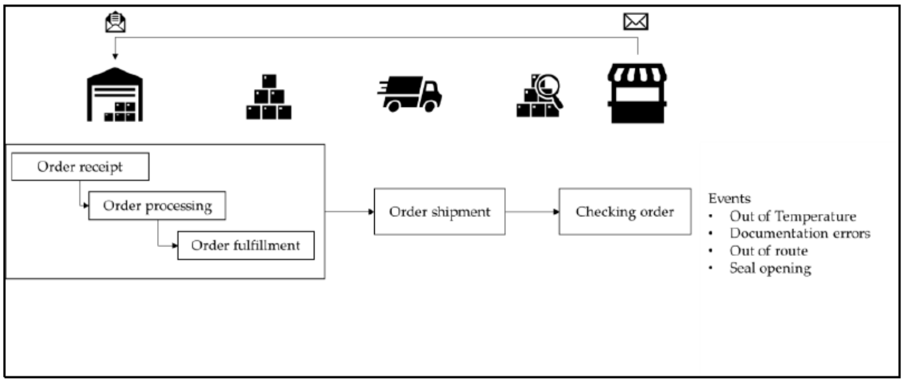


Figure III.2. *Order management process for as-is scenario.*

III.2.2. To-be scenario

The to-be scenario considers the combination of RFID, IoT, BT and smart contracts to test and compare the results of the as-is scenario. These technologies are implemented for each actor. RFID sensors allow acquiring information related to the environmental conditions of the cheese wheels in the dairy farm's warehouse and in the carrier's truck. IoT allows the transfer of data from sensors to the DLT. BT securely and permanently records transactions. The recorded transactions are visible to supply chain members who have authorized access. Within the DLT, the data is recorded in a decentralized P2P system in a secure way despite centralized client server systems. Smart contracts automate some order management activities. The purchase order is generated by the retailer by the activation of a smart contract that gives a passphrase for the actors involved. This passphrase is linked to the order requested from the dairy farm, and the retailer will provide it to the carrier at the time of delivery to unlock the cheese wheels. The order acceptance authorization is verified after the authentication on blockchain using both public and private keys.

For warehouse management, RFID sensors, IoT and blockchain allow virtual and physical warehouses to be aligned in real time. The times for checking the availability of goods in the warehouse are reduced and modelled with a normal distribution. Shipping times between dairy farms and retailers remain the same. However, RFID and IoT technologies have been installed within the vehicle to monitor the shipment. Once the goods have arrived at their destination, the carrier needs the passphrase that the retailer will have to provide. An incorrect passphrase generates an unfulfilled order that is promptly reported to the dairy farm that will oversee the problems solving. In this scenario, the event of a non-compliant product is quickly reported to all the actors who have authorized access on the platform. The goods return immediately to the dairy farm which will contact to send the cheese wheels back. In this case, the documentation is in digital format. Figure III.3 shows the activities for each actor for the to-be scenario. Table III.3 highlights the time differences between the two scenarios with the respective probability distributions for each activity.

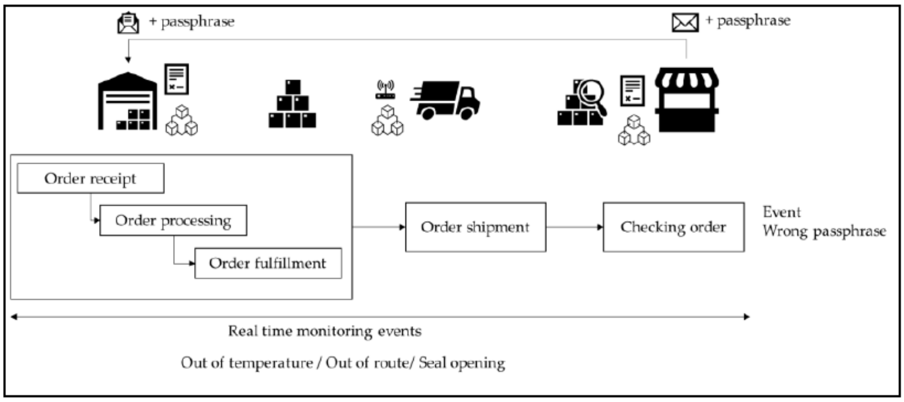


Figure III.3. *Order management process for to-be scenario.*

Table III.3. *Input parameters for simulation models.*

Input	Steps	Probability	As-is	To-be
Order management (DF)	Receipt Processing Fulfilment	Normal distribution (ND)	8 hour; 1 hour	4 hour; 30 min
Order management (C)	Shipping	ND	30 min; 5 min	30 min; 5 min
Order management (R)	Checking	Triangular distribution (TD)	20 min; 40 min; 30 min	/
Non-compliant products management	Out of temperature	TD	10 min; 25 min; 20 min	/
Non-compliant products management	Wrong Documentation	TD	10 min; 30 min; 15 min	/
Non-compliant products management	Out of route	TD	1 hour; 2 hour; 1,5 hour	/
Non-compliant products management	Seal opening	TD	6 min; 15 min; 12 min	/
Non-compliant products management	Wrong passphrase	TD	/	1 min; 5 min; 3 min
Level of service			96%	96%
Out of temperature			1%	1%
Wrong documentation			1%	/
Out of route			1%	1%
Seal opening			1%	1%
Wrong passphrase			/	1%

III.3. Results

Table III.4 illustrates the findings from the simulation scenarios. The service level considered is 96% for both scenarios. Events for non-compliant products occur with the same probability in both scenarios. The number of orders processed in the to-be scenario is higher than in the as-is scenario. Smart contracts allow for greater responsiveness in reply to order receipt and fulfillment. The time for perfect orders is the time that elapses between the generation of the retailer's order until the goods are received after the goods quality control. The events for non-compliant products are the time from the generation of the retailer's order to the confirmation of non-compliant orders according to the following factors: out of temperature, out of route, seal opening for both scenarios, while wrong documentation and wrong passphrase depending on the scenario considered. The evaluation of non-compliant product events of as-is scenario take place as a result of quality control. In the to-be scenario, digitization and constant monitoring of parameters allows for reactive and optimized decisions to be applied when these events occur. In both scenarios, the time between the order generation and the goods arrival to retailer is 2 days. The to-be scenario has a positive variation in the average time of 1.4% for the achievement of perfect orders. The average time saved for managing an order is approximately 72 min. Moreover, there is a 3.2% time reduction for non-compliant products events. The results show the time variations that the to-be scenario can have on these events.

Table III.4. *Results from the simulation scenarios.*

KPI	As-is (h)	To-be (h)	Time saving (min)	Δ%
Average time perfect order	**41.50**	**40.97**	**36**	**1.4%**
Average time out of temperature	41.59	40.73	52	2.1%
Average time opening seal	41.78	40.53	75	3.0%
Average time out of route	42.94	40.77	131	5.1%
Average time documentation errors	42.00	-	66	2.6%
Average time wrong passphrase	-	40.89		
Average time events for non-compliant products	**42.07**	**40.72**	**81**	**3.2%**
Average total time saving	**41.96**	**40.76**	**72**	**2.9%**

III.3.1. Sensitivity analysis

The sensitivity analysis used is the factors' prioritization (Borgonovo and Plischke, 2016). The parameters are average delivery time to the retailer, time to re-order and number of products for an order. Table III.5 shows the variations of these parameters. The average delivery time to the retailer affects the time savings when the order shipping activity takes longer, while short-term variations are negligible. In particular, the higher the distances, the higher the impact on time saved on the verification of non-compliant products. The time to reorder of the cheese wheels reduces as the interarrival time increases. Indeed, the lower the reorder times, the higher challenging the order management department has to fulfill orders faster. The to-be scenario automates and standardizes many operations, reducing the employees' workload. The different number of cheeses required in an order has an impact on the time-saving percentage because handling several products involves more checks by the order management department. The use of IoT and RFID reduces complexity because there is a continuous alignment between physical availability in the real and virtual warehouse.

Table III.5. *Parameters varied for the sensitivity analysis.*

Parameter	Value	% Time saving
Delivery time	20 min	1.4%
	25 min	1.6%
	35 min	1.3%
	40 min	4.1%
Time to re-order	1 day	9.7%
	2 days	8.2%
	4 days	7.0%
	5 days	3.7%
Number of products for an order	2	5.1%
	3	6.0%
	5	8.4%
	6	9.8%

III.4. Discussions

The simulation model among the three players allows understanding the potential advantages that the integration of multiple technologies can bring to supply chain operations. In particular, the integration between the various technologies significantly increases the speed on the operations and reduces the number of manual activities. In the as-is scenario, more manual work is required to check the status of an order, which leads to greater coordination problems. The lack of standardization can produce data management issues. The manual checking and acquisition of orders can lead to errors such as data duplication. For this reason, the fulfilment of an order can leads to time delays. In the as-is scenario, periodic alignment activities of the physical warehouse with the virtual warehouse result in time loss. Checking activities are carried out on goods arrival by the retailer. This produces an increase in the average times for managing events related to non-compliant products. The to-be scenario considers BT and smart contracts that enable a unique communication channel among the three players starting from the order generation by the retailer. IoT and RFID allow greater control between the real and virtual warehouse. In this scenario, the non-compliant products management saves time by 3.2%. The analysis contributes to deepen the integration issues of technologies for a better SCM. Smart contracts allow automating order management through predefined rules. Moreover, by applying advanced rules it is possible to manage more activities automatically. The distributed ledger allows keeping the transactions history and a secure and complete data visibility.

Comparing the two scenarios, 81 minutes were saved for the non-compliant products management and an average of 72 minutes for each perfect order. In the second scenario, operational inefficiencies were eliminated by employing a single platform for communicating orders. The non-compliant products management is no more the retailer's responsibility. The technologies control and monitor the entire system. As for the average times for each non-compliant product, the greatest impact is when the carrier doesn't arrive at its destination. In the to-be scenario the retailer tracks his shipment, allowing for a quick intervention. Table III.6 summarizes the characteristic aspects of each actor in both scenarios.

Table III.6. *Advantages and disadvantages for each actor in both scenarios.*

Actors	As-is scenario	To-be scenario
Dairy farm	• Non-standardized communication; • Lack of product traceability; • Periodic manual alignment of the goods in the physical warehouse with the virtual one; • Long waiting times for non-compliant product management; • No additional costs for digitalization; • Lack of skilled resources for data management.	• Single secure and common platform for the communications exchange on a distributed ledger; • High product traceability; • Advanced goods alignment between the physical and virtual warehouse; • Quickly intervention on the occurrence of non-compliant products; • Losses reduction due to unnecessary bureaucratic paperwork and human error; • High transparency and increase in the dairy farm's reputation; • Implementation and integration cost of different technologies; • Hiring qualified personnel for innovative technology management.
Carrier	• Lack of goods monitoring during the shipment.	• Constant goods monitoring during the shipment; • Implementation and integration cost of different technologies; • Hiring qualified personnel for innovative technology management.
Retailer	• Quality control activity managed by a resource; • Non-standardized communication; • Low reactivity to the occurrence of non-compliant products.	• Delivery times reduction for perfect orders; • Single secure and common platform for the communications exchange; • Reduction of responsibilities for quality control; • Hiring qualified personnel for innovative technology management.

III.4.1. Managerial implications

The chapter offers a comprehensive portrait of the integrated use of different technologies by evaluating the time performance of supply chain operations among three actors. The integration of these technologies allows reduced delivery times for perfect orders, continuous goods monitoring and can reduce losses due to manual error. These technologies can improve productivity, increase competitiveness in B2B companies and reduce the time spent for monitoring activities. Smart contracts automate various procedures and workflows, potentially causing intermediate jobs to disappear, adding to traditional unemployment. This chapter shows how emerging technologies can be used to solve specific supply chain operations, in this case order management and non-compliant product management. The absence of intermediaries reduces transaction costs, thus reducing waste of time. Human errors are reduced using smart contracts that facilitate the automation of operations. Verification costs and monitoring costs are minimized. The data transparency, guaranteed by the complete product traceability, enables key factors of trust between the actors. The increased transparency and speed of response guarantees a better company's reputation.

Blockchain would allow managers to set custom rules on order's activities and provide secure and faster time responses to supply chain actors. This chapter provides guidelines for managers and decision makers to implement and manage these technologies. Companies should take advantage of innovative technologies by pursuing sustainable development goals. Of course, revolutionizing business organization can cause various issues in the early period. However, migrating to innovative technologies can benefit partner relationships and business reputation. The integrated adoption of these technologies is still slow as knowledge and skills in these fields are inadequate. The use of these technologies for SMEs (Small and Medium size Enterprises) is not taken for granted as it can be expensive in terms of implementation costs and these technologies should integrate with already existence IT systems. To date, the real cases are still few, and it is difficult to understand the actual opportunities and challenges of the integration of these technologies.

III.4.2. Future directions and limitations

This chapter have evaluated the effects of integrating emerging technologies on order management and non-compliant product management. It demonstrates the time savings that the integration of specific technologies brings to modern supply chains and contributes to SCM literature. The simulation of the cheese supply chain is due to the fact that agri-food products need detailed information on origin and provenance.

The limitations of this research concern the analysis of scenarios through the simulation tool. The chapter does not evaluate the implementation costs, such as technology infrastructure and human resources. In the next chapter, the same approach will be extended to other areas of SCM. In this simulation, the time taken to process an order is short. The potential impacts would be more significant if the model was based on routes with longer distances and therefore higher times.

Future research could study innovative ways to combine these technologies for SCM. In addition, it would be interesting to evaluate the impact on sustainability associated with the integration of these technologies. A potential development could concern the exploration of the timing in cross-border shipping, in which can be considered various actors and parameters. In the next chapter it will provide a further example of a simulation model that considers multiple actors for export shipments by implementing the Vendor Managed Inventory strategy.

Chapter IV – Blockchain, IoT, RFID and VMI strategy: three simulation models

IV.1. Introduction

Today, SCM face several issues in terms of market complexity (Jæger et al., 2021), sustainable development (Siddh et al., 2021), cross border shipments (Stojanović and Ivetić, 2020), partnership (Ghobakhloo et al., 2021), production planning (Cañas et al., 2021), resilience (Ivanov et al., 2019) and information sharing (Birkel and Müller, 2021). These challenges lead firms to innovate and implement new technologies and IT systems (Agrawal et al., 2022). Specifically, it is important to manage commercial and information exchanges among supply chain actors, minimizing costs and time and ensuring higher quality of products and services (Omar et al., 2020). Considering the Industry 4.0 paradigm, the current scenario includes the combination of new technologies that automate several activities in order to enhance production and logistics operations of each supply chain member (Galanakis et al., 2021; Tang and Veelenturf, 2019). Therefore, monitoring data is fundamental for making decisions and plans for improving business performance. There has been an exponential growth in the data availability and new technologies that will enable efficient inventory policies. For instance, Vendor Managed Inventory (VMI) allows upstream actors to plan the goods for downstream actors (Disney and Towill, 2003a). VMI reduces inventory costs and strengthen the relationships among partners (Disney and Towill, 2003b).

However, the application of VMI strategy faces challenges such as data integrity and transparency, data accessibility, information delay and server-client systems (Kolb et al., 2018). The integration of innovative technologies in SCM can be helpful in overcoming coordination challenges. For example, drones and sensors could collect data on production, shipments and warehousing (Sharma et al. 2020). This data can be sent to decentralised servers, using IoT systems, to make informed and appropriate decisions (Lezoche et al., 2020). The use of decentralised systems allows for greater security and redundancy of data (Feng et al., 2020). Researchers are considering BT to overcome these issues. In particular, BT could enable the applications on VMI (Casino et al. 2019a). In literature, the research has hypothesized a time reduction for supply chain activities using blockchain without verifying the effects in the long term because real cases are still few. In order to be used efficiently in supply chain activities, BT should be supported by external tools, that collect data as aforementioned evaluate in *Chapters II* and *III*.

The purpose of this chapter is to evaluate the time performance that the integration of BT, IoT and RFID brings to a cheese supply chain through a simulation model. Three scenarios are compared, one without the technologies, one with the use of the technologies and a third with the application of the VMI strategy. The actors involved are the dairy company, the 3PL, the wholesaler, three retailers and the end customers. The rest of the chapter includes section IV.2. describing the simulation scenarios, while section IV.3. shows the research results. Section IV.4. provides further clarification of the results from a theoretical point of view and illustrates the managerial and practical implications of this research. Future research and limitations close the chapter.

IV.2. A simulation model for an integrated supply chain

Based on simulation studies in the scientific literature, three models of the cheese supply chain were developed: 1) as-is scenario without the use of technology and application of the VMI strategy (Bottani and Montanari, 2010; Muravev et al., 2019); 2) to-be scenario adopting BT, IoT, RFID and smart contract (Lohmer et al., 2020; Longo et al., 2019; Martínez-Navarro et al., 2019; Tozanlı et al., 2020); and 3) a further to-be scenario adding the VMI strategy (Dasaklis and Casino, 2019; Omar et al., 2020). Figure IV.1 shows the design and development steps.

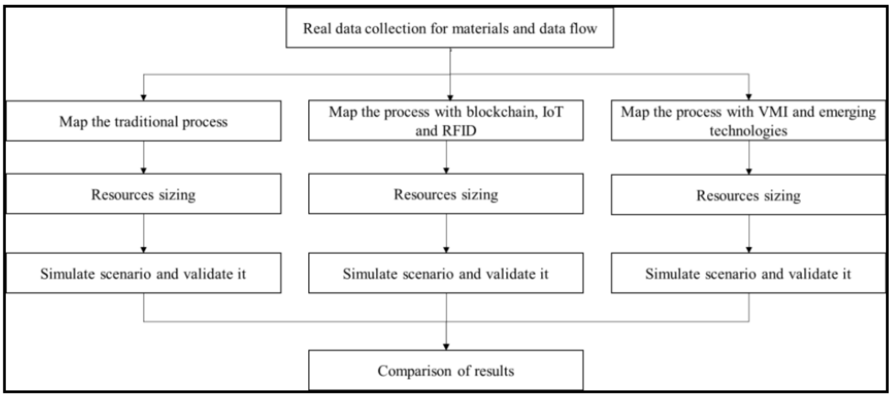


Figure IV.1 *Simulation design steps*

IV.2.1. Simulation model and data collection

The simulation is based on the export of Italian cheese from a dairy farm located in Italy. The SCM areas considered within the simulation are logistics, inventory management and order management. The input data comes from literature contributions (Helo and Shamsuzzoha, 2020; Lohmer et al., 2020; Longo et al., 2019; Martinez et al., 2019), cheese consortium reports (Parmigiano Reggiano, 2022) and online reports (ISTAT, 2022).

IV.2.2. Design of the simulation model

The parameters input and output, warm-up phase, model execution time and number of replicas were considered (Carson, 2004). The simulation parameters are shown in Table IV.1.

Table IV.1. *Parameters considered in the simulation models.*

Parameter	Description
Runtime	0-18 months. Warm-up phase is excluded.
Input	Order management activities for each actor and loading/unloading activities of the goods managed by a 3PL.
Output	12 output parameters for each actor. • Dairy farm's order preparation; • 3PL's shipping time; • Time to order for the wholesaler; • Unfilled orders, level of service and lead time for each retailer.
Number of runs	10 replicas with precision 0.01

IV.2.3. As-is model

The simulation involves a dairy farm (DF), a 3PL, a wholesaler (W) and three retailers (RA, RB and RC) (Figure IV.2). When the customer arrives at the retailer, the quantity of cheese is compared with the retailer's inventory and, if possible, the demand is fulfilled, otherwise the missing demand is recorded as an unfilled order. The stock level is checked before working hours and, if an order is required, the retailer makes the purchase from the wholesaler. The procurement is based on a reorder time and a fixed quantity. Missing quantities are recorded as unfilled orders. Periodically, the wholesaler checks the availability of its inventory and requests the necessary quantities of cheese wheels for the dairy farm.

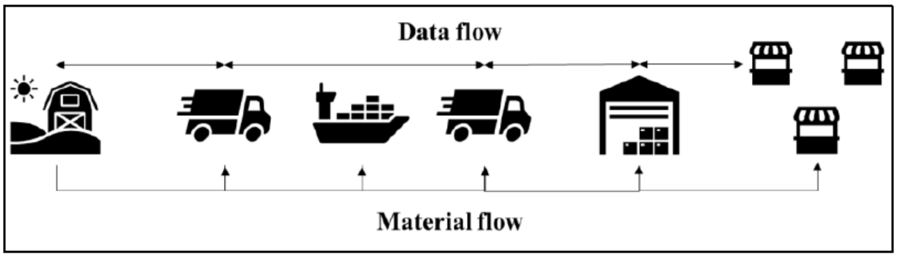


Figure IV.2. *As-is scenario scheme.*

Milk supply and dairy farm's production phase

The milk supply phase consists of the trucks' arrival, which unload the quantities of milk at the dairy farm. The procurement phase was designed and sized according to the production phase. Specifically, the dairy farm has a production capacity of 24 cheeses per day. A cheese wheel of Parmigiano Reggiano weighs about 40 kg and requires 550 litres of milk, of which 275 in the morning and 275 in the evening. Each day, it is needed to stock up on 6,600 litres of both evening and morning milk. When the quantities of milk are present, the 21-day production phase can begin. After the production phase, there is the storing of the cheese wheels within the warehouse.

Dairy farm's warehouse and inventory management

The warehousing phase of the dairy farm represents a fundamental activity in the cheese supply chain, as in this phase the cheeses are aged and then sold. The warehouse has six different activities: **storing, order management, picking, checking** and **order preparation** (packing and shipping).

The **storing** phase consists in inserting the cheese wheels into the shelving where they are aged. The warehouse worker uses the forklift to place the cheese wheels on the shelves. Once the cheese wheel has been captured, the forklift reaches the position where it will have to insert the cheese wheel. At this stage, the products arriving in the warehouse are placed inside the shelving. This activity is carried out by forklift which can work at any time of the day.

Before carrying out the operations related to the product picking phase from the warehouse, there is the **order management** step performed by an order clerk. When the order arrives, an order clerk should check the presence of ready-made cheese wheels in stock and the possibility of fulfilling the order or not. If the available products allow meeting the demand, then the order clerk proceeds with its activities and sends the information to the warehouse worker. Once received the order, it should be managed by a warehouse worker who verify the availability of the required quantity of the cheese wheels and organize the activities needed for the order fulfillment. Orders are set on a fixed quantity but can arrive at variable time intervals that depend on the needs of the wholesaler. At the end of this phase, a transport request is sent to 3PL which will have to send the trucks that will be used for shipping.

The **picking** activity is carried out using the forklift which picks up the products following a FIFO logic and carry them on the storage area from which they will be picked up by warehouse worker in charge of the quality control operations. **Quality checking** should be performed to ensure that products sent to customers are quality products and have no problems. The resource responsible for carrying out these activities is the quality inspector who decides whether the products can be sold. If successful, the products are branded with the Parmigiano Reggiano logo. After the check, if there are non-compliant products, other products are taken in a number equal to the rejects. The information flow allows signalling to the system the presence of rejects and the need to pick up further cheese wheels. In this way it is possible to complete batches to be sent to customers.

The last activities in the warehouse are products **packaging** and **shipping**. At the end of the control phase, the cheese wheels are picked up by the warehouse worker who brings them to the packing area. In this phase, the cleaning of the cheese wheels and their packaging takes place before placing them on the pallets to be sent to the wholesaler. Finally, the pallets should be loaded onto the truck to be used for shipping. Figure IV.3 shows the dairy farm's activities.

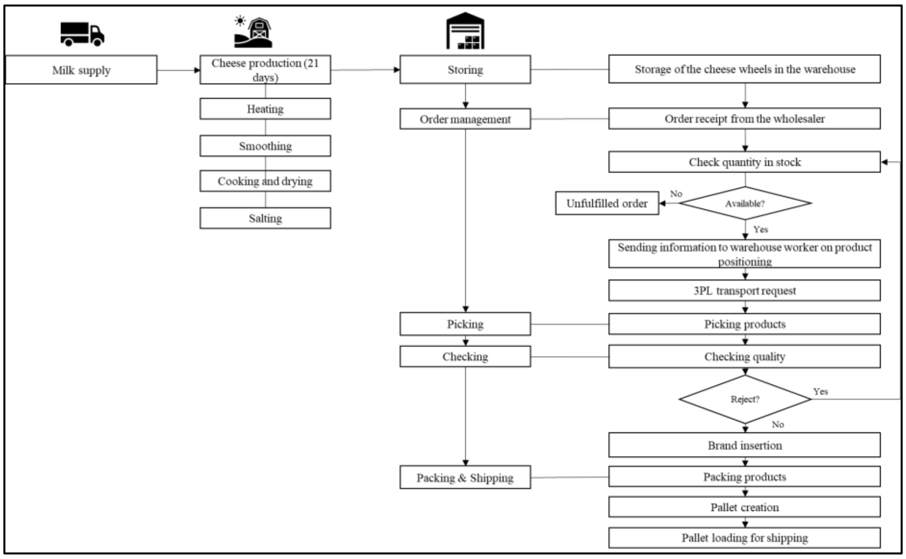


Figure IV.3. *Activities' scheme of dairy farm's production, warehouse and inventory management.*

Table IV.2 illustrates the dairy farm's simulation features.

Table IV.2. *Simulation features of the as-is scenario for the dairy farm.*

Area	Activities	Resources	Equipment	Description	Time
Order management	Order receipt; Order processing; Order generation	Order clerk	Excel; e-mail; phone	Order management is handled by the order clerk. He checks the cheese wheels available in the warehouse and sends data to the warehouse worker who should handle physical activities for the shipping. He supervises the relationships with the 3PL.	ND (1h; 2min)
Inventory management	Storing	Warehouse worker	Stacker crane	A warehouse worker loads cheese wheels into the shelves.	TD (18 sec; 30 sec; 1 min)
	Picking & Checking		Forklift	Warehouse worker who oversees goods transportation for the quality check.	TD (1 min; 1.5 min; 2 min)
	Packing			Warehouse worker that deals with packaging. He also provides the goods transportation for loading them into the truck.	TD (50 sec; 1 min; 1.20 min)

3PL

The transportation process involves the cheese wheels delivery from a dairy farm situated in Reggio Emilia to a wholesaler situated in Badalona. The starting process is given by the transportation order that the dairy farm makes to 3PL once it has verified that it has the goods available to meet the request of the wholesaler. Following the arrival of the transport request, the 3PL order clerk evaluates the shipping, by checking the availability of trucks and drivers.

Once the shipment has been planned, the driver will go to the dairy farm's warehouse to **load the cheese wheels**. Before the driver arrival, the cheese wheels are placed on pallets and brought to the shipping area by the warehouse worker. After that, the packages are loaded into the truck. The seal is attached to the pallet (this operation is necessary in order to prevent the products from being tampered with during the shipment). The documentation shows the unique code of each seal. Once the **shipment** has started, the driver will go to the port of Livorno. The truck and the driver will be boarded and once arrived at the port of Barcelona, the driver will deliver the goods to the wholesaler.

Upon arrival at the wholesaler in Badalona, the driver delivers the goods to the warehouse worker. He is in charge of verifying the integrity of the packages, seals and correct documentation. Next, the documentation is signed for the certification and authorization related to goods arrival. At this stage, if the documentation generated is not delivered to the administrative office, it is not possible to proceed with the billing of the service provided, and the order cannot be closed. In the as-is scenario, it is necessary to wait a driver to return to the 3PL headquarters and deliver the documents. Following these operations, the information flow is extinguished and the model relating to the dairy farm-wholesaler transport phase is completed. Figure IV.4 shows the 3PL’s activities. Table IV.3 illustrates the 3PL’s simulation features.

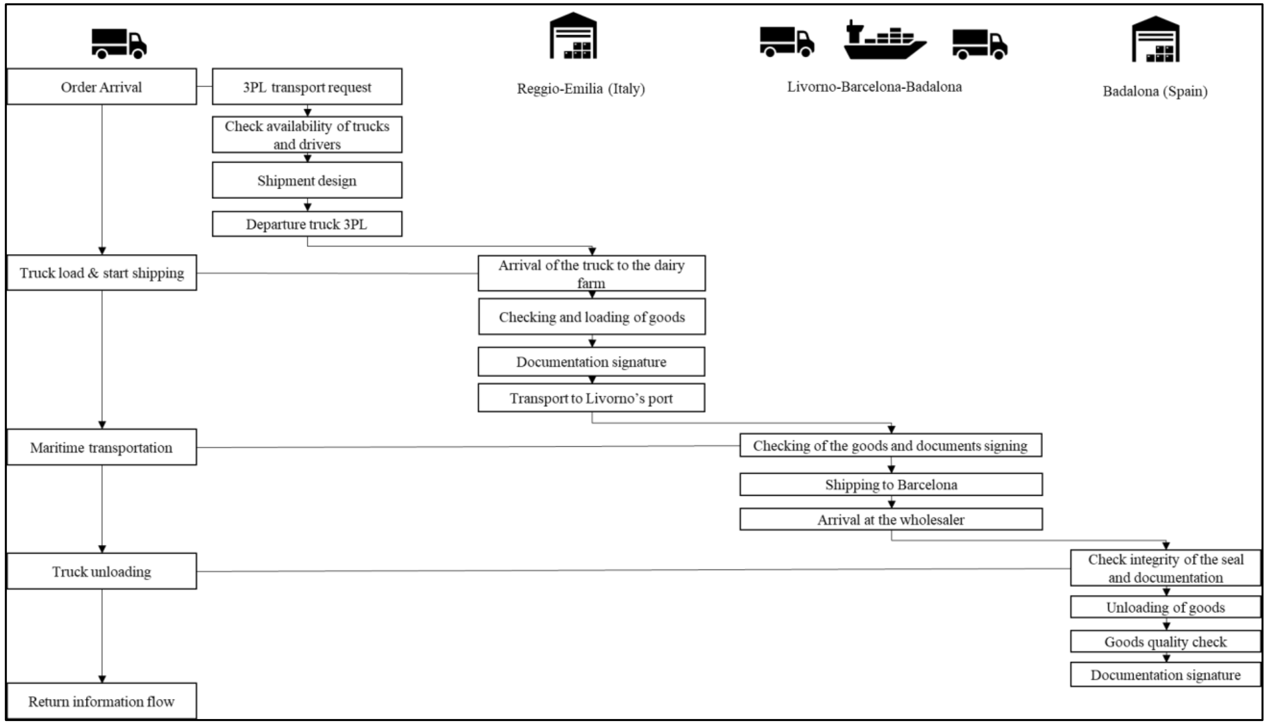


Figure IV.4. *Logistics activities' scheme.*

Table IV.3. *Simulation features of the as-is scenario for the 3PL.*

Area	Activities	Resources	Equipment	Description	Time
Order management	Order receipt; Order processing; Order generation	Order clerk	Phone; Excel; e-mail	Order management is handled by the order clerk. He checks the trucks and drivers' availability.	ND (1 h; 2 min)
Logistics	Checking pallet	Driver	Truck	Driver responsible for checking pallets, verifying the documentation, loading and shipping goods.	ND (15 min; 1 min)
	Signing pallet				ND (5 min; 1 min)
	Loading pallet and Shipping		Truck		TD (4 h; 4 h and 20 min; 4h and 40 min)
	Maritime Transportation		Ship		ND (2 h; 5 min)
	Unloading pallet			Driver responsible for unloading pallets.	ND (40 min; 2 min)

Wholesaler

One of the objectives of the wholesaler is to achieve economies of scale. The supply takes place at fixed quantities, at a level that allows the transport container to be fully saturated. This reordering quantity was sized equal to 275 cheese wheels. The reordering time horizon was assumed to be constant, with exceptions related to the quantities in the wholesaler's warehouse. At each reorder period, which is equivalent to about eight days, the order clerk checks if the number of stocks in the warehouse exceeds a reorder value and, in this case, does not process the order for that period. The reordering level is sized to satisfy market demand for a time interval equal to the maximum value at time to order. In addition, a safety stock of 10% was considered to avoid stock out.

The order management includes the inbound and outbound flows to retailers. The order management processes between the wholesaler and retailers will be described in more detail in the next sections regarding the description of the retailers. The outbound logistics phases concern the goods transport from the wholesaler to the three retailers. The logistics phases are entrusted to the internal resources of the wholesaler, who will take care the transportation to the retailers. To optimize loading and shipping, the delivery to the three retailers will be carried out with the multidrop strategy. The times considered describe the times required for transport and delivery respectively to retailer A, then B and finally C, which are located in the city of Barcelona. These times include load and document verification. Table IV.4 illustrates the wholesaler's simulation features.

Table IV.4. *Simulation features of the as-is scenario for the wholesaler.*

Area	Activities	Resources	Equipment	Description	Time
Order management	Order receipt; Order processing; Order generation	Order clerk	Phone; excel; e-mail	Order management is handled by the order clerk. He checks the cheese wheels available in the store and sends data to the warehouse worker who should handle shipping operations. He supervises the relationships with the dairy farm.	ND (1 h and 30 min; 2 min)
Inventory management	Storing	Warehouse worker	Stacker crane	Warehouse worker in charge of loading cheese wheels into the shelves.	TD (18 sec, 30 sec, 1 min)
	Picking & Checking		Forklift	Warehouse worker in charge of checking quality.	TD (4 min, 5 min, 7 min)
	Packing			Warehouse worker responsible for packaging. In addition, he loads the pallet into the truck.	TD (50 sec, 1 min, 1.20 min)
Logistics	Checking pallet	Driver	Truck	Driver responsible for checking packages.	ND (15 min; 1 min)
	Shipping truck for retailer A			Driver responsible for shipping goods to the retailer A	ND (30 min; 5 min)
	Shipping truck for retailer B			Driver responsible for shipping goods to the retailer B	ND (50 min; 4 min)

Shipping truck for retailer C	Driver responsible for shipping goods to the retailer C	ND (60 min; 5 min)

Retailers

The simulation considers three retailers situated in the metropolitan city of Barcelona. RA, RB and RC have similar behaviour, with differences in terms of customer arrival rate and distance from the wholesaler. In particular, the activities modelled are orders management, products handling and selling.

Following a checking activity in the warehouse, the retailers order at fixed quantities and time periods. If the number of stocks present exceeds a reorder level during the period, the order is not processed. The reordering period was set variable, with a triangular distribution, between nine and ten days, based on the quantities purchased and sold. The order clerk checks whether the quantity in stock is lower than a reorder level equal to 4 for retailer A, 3 for retailer B and 2 for retailer C, if it is lower it is fulfilled the order. The order fulfillment by the retailer's commercial department is followed by the wholesaler's order management. When the order arrives at its destination, it is necessary to carry out the operations of unloading the goods and managing the cheese wheels. It has been hypothesized that the sale of Parmigiano Reggiano takes place in standard portions weighing 200 grams, therefore a cutting phase is necessary, in which 200 mono-packs are obtained starting from the 40 kg cheese wheel. After being handled and prepared in mono-packs of 200 grams, the cheeses are stored to be sold as soon as the customer requests the product. The number of customers was modelled based on the opening hours of the supermarket. For retailer A, they are equal to 1,600, 1,200 for B and 800 for C. It was assumed that the inter-arrival time is dictated by an Exponential Distribution (ED) with parameter λ (customers per hour) equal to the number of daily arrivals divided by 12 hours. Figure IV.5 shows the wholesaler and retailers' activities.

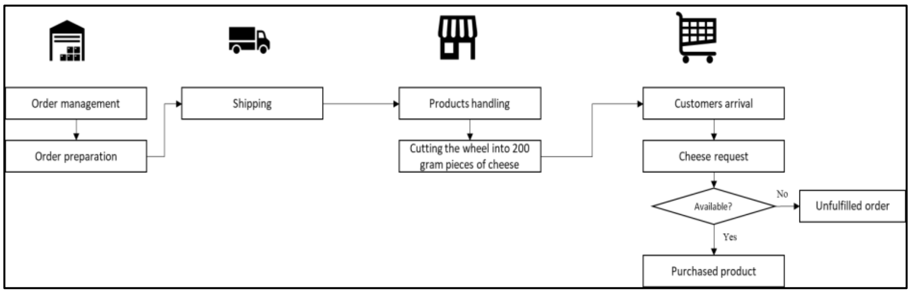


Figure IV.5. *Wholesaler and retailers' activities.*

Table IV.5 illustrates the retailer's simulation features.

Table IV.5. *Simulation features of the as-is scenario for the three retailers.*

Area	Activities	Resources	Equipment	Description	Time
Order management	Order processing; Order generation	Order clerk	Excel; e-mail; phone	Order management is handled by the order clerk. He checks the cheese wheels available in the store and sends data to the wholesaler for reordering cheese wheels.	ND (1 h; 2 min)
Inventory management	Products handling	Worker	Forklift	The warehouse worker handles the incoming goods, checking them and transporting them to the retailer, ready to be cut.	ND (15 min; 1 min)
Selling Retailer A		Cashier		The cashier sells cheese mono-portions.	Exponential distribution (ED) (1600 customers/day)
Selling Retailer B		Cashier			ED (1200 customers/day)
Selling Retailer C		Cashier			ED (800 customers/day)
%Purchased Products A, B and C					TD (0.03; 0.05; 0.07)

IV.2.4. To-be model

This scenario involves the use of BT, IoT and RFID. Specifically, Hyperledger Fabric is used as a blockchain where each actor has a key pair to authorise transactions (Hyperledger, 2022). All transactions exchanged between actors are stored within the blockchain. IoT and RFID allow controlling and collecting data on the storage of cheese wheels within each actor's warehouse and trucks and to send them in the distributed ledger. The stock level is updated daily and there is an alignment between the virtual and the physical warehouse. In this scenario, smart contracts automate various activities related to order management. For example, when the stock level is below the customer's needs, an alert signal is used to predict the stock-out and authorise the reordering of cheese wheels. For each exchange of products, documents and events between actors, there will be a transaction in the platform that monitors the complete tracking of activities. Acceptance of products takes place through the use of keys and passphrases managed by the implemented smart contracts. Events such as goods position, delivery times, critical temperature and humidity conditions are recorded within the blockchain to monitor events in real time.

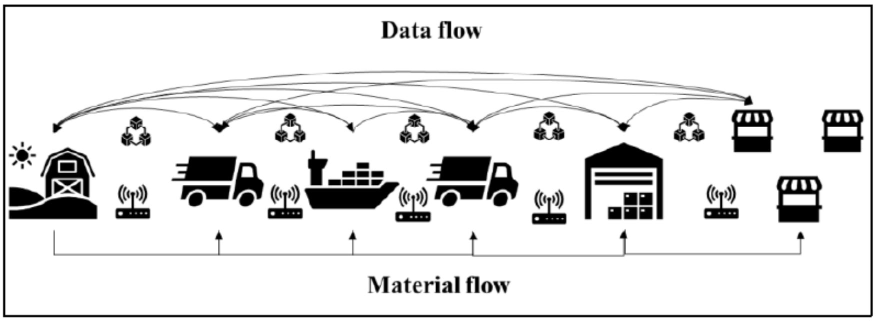


Figure IV.6. *To-be scenario scheme.*

Dairy farm's warehouse and inventory management

In the second scenario, blockchain and smart contracts are integrated with two other technologies, specifically the IoT and RFID with the aim of measuring performance. Starting from the as-is simulation model, changes have been made shown in Table IV.6. The difference between the two models mainly concerns the orders and inventory management.

In this scenario, IoT and RFID automate the collection of data and transfer them to a common platform that is the blockchain. Communication takes place on a single platform and efficiency is increased through the use of smart contracts that automate the handling of orders according to previously agreed contractual agreements. In this case, all manual inventory control and verification operations were eliminated. Supply chain members can monitor the status of the cheese wheels in real-time. This allows the inventory to be updated from time to time regarding the products' quantity in the warehouse. BT updates and makes the inventory information available to all the members. In this way, orders are managed quickly and precisely.

Table IV.6. *Simulation features of the to-be scenario for the dairy farm.*

Area	Activities	Resources	Equipment	Description	Time
Order management	Order receipt; Order processing; Order generation	Order clerk	Phone; Excel; e-mail; Blockchain, Smart contracts	Order management is handled by the order clerk. He checks the available cheese wheels in the warehouse using blockchain and sends data to the warehouse worker. Then, a warehouse worker should handle operations for the shipping. He supervises the relationships with the 3PL employing a smart contract.	ND (5 min; 30 sec)
Inventory management	Storing	Warehouse worker	Stacker crane; IoT; RFID	A warehouse worker loads cheese wheels into the shelves. RFID and IoT are implemented into the shelves to monitor the cheese wheels conditions	TD (18 sec; 30 sec; 1 min)
	Picking & Checking		Forklift; IoT; RFID; blockchain	Warehouse worker responsible for checking cheese quality.	TD (1 min; 1.50 min; 2 min)
	Packing			Warehouse worker responsible for packaging. Each package has an RFID in order to detect the environmental conditions. The pallet is tracked on blockchain.	TD (50 sec; 1 min; 1.20 min)

3PL

For logistics, the implementation of smart contracts regulates the relationships with the dairy farm and allows the digitization of documents within the blockchain. Among several activities, that are automated with smart contracts, there are orders and the documentation management with a minimization of errors and the number of operators necessary. The documents associated with the export are different (CMR, DDT, packing list, invoice) and during transport they are viewed and modified by different players involved. When documents are digitized, all nodes can view them quickly and securely. They are signed by the supply chain actors with their private key and, after the transaction has been verified, they are stored in the system. In this case, RFID and IoT allow obtaining significant advantages and improvements for supply chain performance. The digitalization of communication allows the elimination of paperwork and multiple bureaucratic procedures. The digitized and shared documents allow a reduction of errors and associated problems. Table IV.7 illustrates the 3PL's simulation features.

Wholesaler and three retailers

IoT, RFID, blockchain and smart contract have also been implemented within the wholesaler and the three retailers. Most activities remained unchanged, but the activities related to order management documentation signature have changed. The activities are shown in Table IV.8 and IV.9.

Table IV.7. *Simulation features of the to-be scenario for the 3PL.*

Area	Activities	Resources	Equipment	Description	Time
Order management	Order receipt; Order processing; Order generation	Order clerk;	Excel; e-mail; phone; blockchain; smart contract	Order management is handled by the order clerk. He checks the trucks and drivers' availability on blockchain.	ND (10 min; 30 sec)
Logistics	Checking pallet	Driver;	Truck, IoT; RFID; blockchain	Driver responsible for checking pallet quality, verifying the documentation using smart contracts, loading and shipping goods. The verification step is done using specific passphrases.	ND (15 min; 1 min)
	Signing pallet				ND (5 sec; 0.5 sec)
	Loading pallet and Shipping		Truck; IoT; RFID; blockchain	Driver that deals with loading goods.	TD (4 h; 4 h and 20 min; 4h and 40 min)
	Maritime Transportation		Ship; IoT; RFID; blockchain	Driver responsible for shipping. The packages are constantly monitored using RFID and IoT	ND (2 h; 5 min)
	Unloading pallet			Driver responsible for unloading packages.	ND (40 min; 2 min)

Table IV.8. *Simulation features of the to-be scenario for the wholesaler.*

Area	Activities	Resources	Equipment	Description	Time
Order management	Order receipt; Order processing; Order generation	Order clerk	Excel; e-mail; phone	Order management is handled by the order clerk. He checks the available goods in the warehouse using blockchain and sends data to the warehouse worker. Then, he handles shipping operations. He supervises the relationships with the dairy farm using a smart contract.	ND (1 h and 30 min; 2 min)
Inventory management	Storing	Warehouse worker	Stacker crane	A warehouse worker loads cheese wheels into the shelves. RFID and IoT are implemented into the shelves to monitor the cheese wheels conditions.	TD (18 sec; 30 sec; 1 min)
	Picking & Checking		Forklift	Warehouse worker responsible for checking quality.	TD (4 min; 5 min; 7 min)
	Packing			Warehouse worker responsible for packaging. Each package has an RFID to detect the environmental conditions. The pallet is tracked on blockchain.	TD (50 sec; 1 min; 1.20 min)
Logistics	Checking pallet	Driver	Truck	Driver responsible for checking pallet quality, loading and shipping.	ND (15 min; 1 min)
	Signing pallet			Driver responsible for verifying the documentation using smart contracts. The verification step is done using specific passphrases.	ND (5 sec; 0.5 sec)
	Shipping truck for retailer A			Driver responsible for shipping goods, constantly monitored with RFID and IoT, to the retailer A.	ND (30 min; 5 min)

	Shipping truck for retailer B		Driver responsible for shipping goods, constantly monitored with RFID and IoT, to the retailer B.	ND (50 min; 4 min)
	Shipping truck for retailer C		Driver responsible for shipping goods, constantly monitored with RFID and IoT, to the retailer C.	ND (60 min; 5 min)

Table IV.9. *Simulation features of the to-be scenario for the three retailers.*

Area	Activities	Resources	Equipment	Description	Time
Order management	Order processing; Order generation	Order clerk	Excel; e-mail; phone; blockchain; smart contract	Order management is handled by the order clerk. He checks the available goods in their warehouses using blockchain and sends data to the warehouse worker. He supervises the relationships with the wholesaler using a smart contract.	ND (5 min; 30 sec)
Inventory management	Products handling	Worker	Stacker crane	The warehouse worker handles the incoming goods, checking and transporting them to the retailer, ready to be cut.	ND (15 min; 1 min)
Selling Retailer A		Cashier			ED (1600 customers/day)
Selling Retailer B		Cashier			ED (1200 customers/day)
Selling Retailer C		Cashier			ED (800 customers/day)

%Purchased Products A, B and C	TD (0.03; 0.05; 0.07)

IV.2.5. To-be model with VMI strategy

In the third to-be scenario, the same technologies as in the second scenario are present but, in addition, the VMI strategy is applied. In this case, the dairy farm has full control over order planning as it has access to the stock data shared by the wholesaler and retailers in real time. The dairy farm is able to appropriately reorder the cheese wheels for each actor. Furthermore, downstream actors have the task of constantly monitoring their stock level, and therefore they need to implement RFID, IoT and blockchain. To avoid storage, scalability and transaction speed problems, an off-chain storage solution (i.e. InterPlanetary File System) is adopted (Baumgart and Mies, 2007). The scenario is similar to the previous models, however in this case the dairy farm plans the order management. The wholesaler and retailers' order management departments are absent.

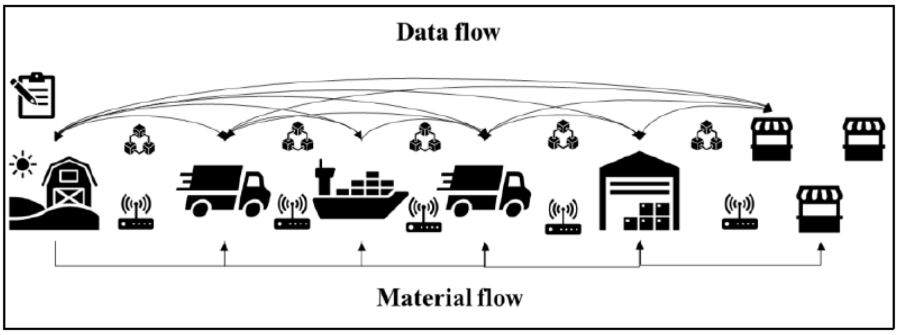


Figure IV.7. *The third scenario with VMI strategy. The dairy farm plans the orders to downstream actors using a smart contract.*

IV.3. Results from the simulation models

Table IV.10 illustrates the results of the three models. Time to order is defined as the time interval for the goods to reach the wholesaler's warehouse. This index considers the time from the wholesaler's order request to the dairy farm until its completion, i.e. the arrival of the cheese wheels in its warehouse (Figure IV.3 and IV.4). For this indicator, the time reduction between scenario 1 and 2 is 12.63%, while it is 13.29% between scenario 1 and 3. Another indicator considered is the dairy farm's order preparation lead time, which is the sum of order handling time, picking, pallet checking, packing time (Figure IV.3). In this case, the dairy farm's order preparation time is reduced by 10.64% between scenarios 1-2 and 12.24% between scenarios 1-3. Unfulfilled orders are those for which the final consumer did not find the cheese package on the retailer's shelf. In scenario 2, unfilled orders were reduced by 92% between scenario 1 and 2. A further reduction of about 70% of unfilled orders appears between scenarios 2 and 3. Finally, the lead time is defined as the time from the retailer's order request to the arrival of the ordered cheese wheels. In this case, there is a lead time reduction between scenario 1 and 2 of 47% due to the automation of smart contracts.

Table IV.10. *Output parameters analysed.*

	Unit	**As-is scenario (Mean)**	**To-be scenario (Mean)**	**To-be scenario (VMI) (Mean)**	**%Δ $_{(1-2)}$**	**%Δ $_{(1-3)}$**	**%Δ $_{(2-3)}$**
Time to order (DF-W)	hour	162	142	140	12.63%	13.29%	0.75%
Lead time order preparation (DF)	hour	89	80	78	10.64%	12.24%	1.79%
Shipping time (3PL)	hour	36	36	36	0.78%	0.83%	0.00%
Consumers (RA)		43630	43743	43804	0.26%	0.40%	0.14%
Unfilled orders (RA)	Cheese mono-pack	1745	201	120	88.48%	93.14%	40.46%
Service level (RA)	%	96.00%	99.51%	99.73%	3.66%	3.88%	0.22%
Lead Time (RA)	hour	29	17	18	42.20%	40.18%	3.50%
Consumers (RB)		32871	32907	32880	0.11%	0.03%	0.08%
Unfilled orders (RB)	Cheese mono-pack	1644	99	16	93.98%	99.03%	83.84%
Service level (RB)	%	95.00%	99.70%	99.95%	4.95%	5.21%	0.25%
Lead Time (RB)	hour	34	17	18	48.93%	46.73%	4.31%
Consumers (RC)		21910	21912	21905	0.01%	0.02%	0.03%
Unfilled orders (RC)	Cheese mono-pack	1205	43	6	96.43%	99.50%	86.05%
Service level (RC)	%	94.50%	99.81%	99.97%	5.62%	5.79%	0.16%
Lead Time (RC)	hour	36	18	18	49.96%	51.16%	2.40%

Figure IV.8 shows the dairy farm’s lead time order preparation. With blockchain, IoT and RFID, order management time is reduced as well as improved by using smart contracts. A significant time reduction is achieved with the VMI strategy, where the dairy farm can plan their activities and production in advance.

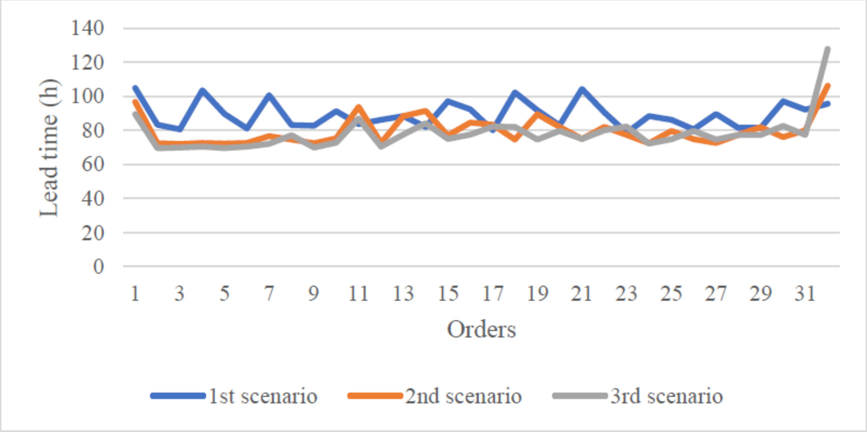


Figure IV.8. *Dairy farm’s lead time order preparation.*

Figure IV.9 shows the time to order for each scenario. In the latest to-be scenarios, it is on average lower than the as-is scenario. Human-manual labour, in the last two scenarios, is reduced and replaced by automated technology. A lower time to order allows satisfying more consumers and for this reason there is less probability of stock out. The percentage of unfilled orders is shown in Figure IV.10. In the last two scenarios, these unfilled orders have significantly reduced.

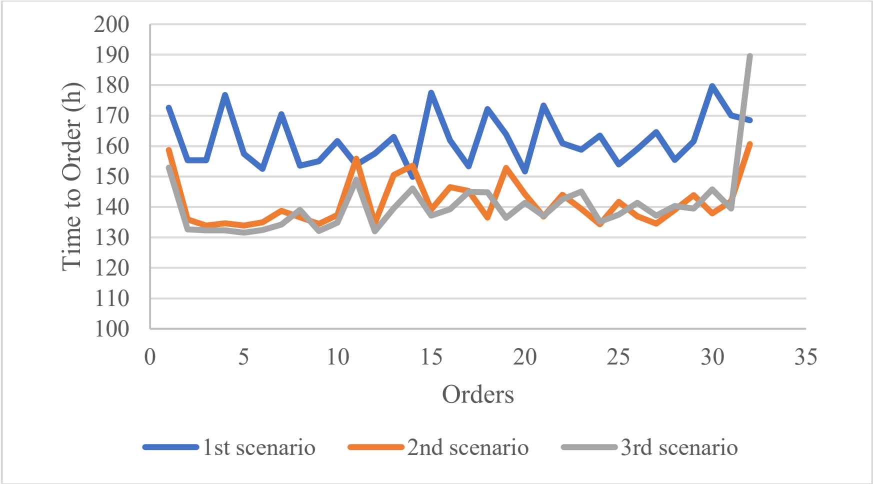


Figure IV.9. *Time to order.*

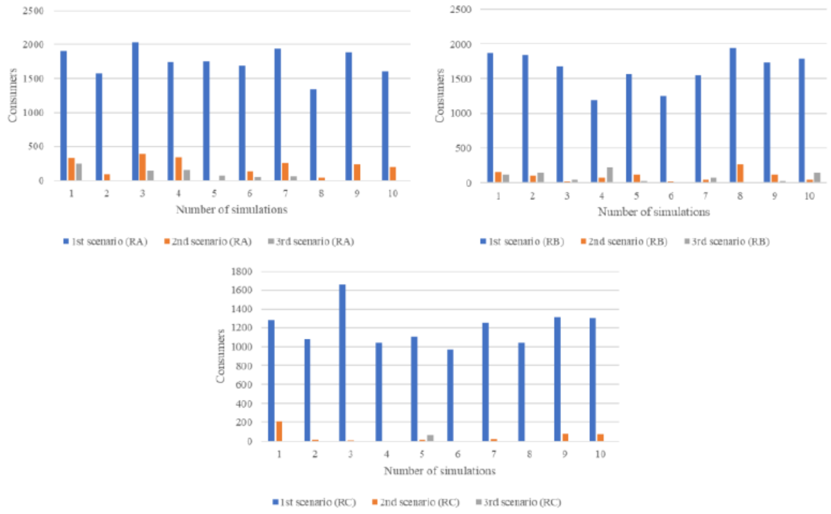


Figure IV.10. *Average unfilled orders.*

IV.3.1. Sensitivity analysis

Three structural parameters were considered to perform the sensitivity analysis: 3PL delivery time, % product purchase and ageing time. These parameters were varied in four steps -20%, -10%, +10% and +20%. The sensitivity analysis shows that the percentage change in the product purchase has a significant impact on the orders filled. The higher the percentage of product purchases, the greater the responsiveness in meeting demand in scenarios where the technologies are adopted and the VMI strategy is applied. Variation in 3PL delivery time and cheese ageing time do not vary for unfilled orders and therefore do not affect the model sensitivity.

Table IV.11. *Sensitivity analysis.*

Parameter	Value	$\%\Delta_{1-2}$	$\%\Delta_{1-3}$	$\%\Delta_{2-3}$
Delivery time (3PL)	-20%	81%	86%	24%
	-10%	78%	78%	0%
	10%	69%	86%	54%
	20%	77%	78%	8%
%Product purchase	-20%	99%	100%	100%
	-10%	90%	91%	10%
	10%	31%	37%	8%
	20%	17%	24%	9%
Ageing time	-20%	89%	100%	100%
	-10%	84%	89%	31%
	10%	96%	97%	20%
	20%	81%	83%	12%

IV.4. Discussions

The chapter has shown what impact the technologies, including blockchain, could have on time performance for SCM. Starting from the various contributions of the scientific literature on blockchain and the integration of different technologies, this chapter provided further insight into time performance on the entire supply chain (Casino, Dasaklis, et al., 2019; Dasaklis and Casino, 2019; Omar et al., 2020). As already analysed in *Chapter III*, the lack of standardisation and the diversity of communication channels increases manual activities, which leads to an increase in order processing time. Often, in the as-is scenario, there is no constant alignment between the real and virtual warehouse, and this can lead to errors in product availability and thus to delivery delays. The main advantage of the to-be configuration of the second scenario depends mainly on the use of RFID and IoT. These technologies enable real-time data acquisition and event tracking. Blockchain is useful for recording these transactions in a single and common platform and making them available to the actors involved in a secure and reliable manner. The application of the VMI strategy improves customer satisfaction by increasing the number of fulfilled orders. However, the time differences of the various indicators are not significant reduced between scenarios. For scenario 3, the reduction of unfilled orders is radically improved. The further adoption of VMI strategy allows the dairy farm to be highly responsive to the final market. In fact, it can easily allocate products and plan for all downstream actors by having full visibility of transactions. Therefore, BT enables the use of the VMI strategy. Regarding the material flow, by combining innovative technologies and VMI strategy on the model, there aren't significant time impacts. Their role is to reshape the information flow. The sensitivity analysis reinforces the hypothesis that by increasing the percentage of product purchases, the use of technologies could strengthen the responsiveness of the supply chain in the final market. Compared to the as-is scenario where planning was mainly based on purchasing history, in the to-be scenarios the transactions sharing through a common platform allows for more accurate forecasting.

This chapter provides an overview of the *ex-ante* time impacts that the adoption of technologies, including blockchain, can have on warehouse, logistics and order management activities. It provides further details to understand the convenience of adopting or not BT. Research has shown how blockchain can be considered an enabler for the application of the VMI strategy by providing time and order fulfilment advantages. However, open questions remain linked to the integration and interoperability of these technologies and the degree of technical expertise required to manage them properly. First, further studies should explore into the implementation costs of these technologies and investigate the impact for each actor and area of the SCM (will be discussed in the next chapter). Second, it would be interesting to understand how these technologies could be used to improve supply chain resilience in pandemic and catastrophic conditions.

The main limitations of this study depend on the simulation method and the specific case study. In particular, the analysis is limited to the export of a single product and does not include the network of several players. Moreover, the simulation focuses only on some actors and not on all activities for each actor. Finally, extraordinary events such as natural disasters (fire, earthquakes, floods), computer or communication system blackouts, disruption of the transport network, failure of third parties to provide services, loss of human resources, industrial conflicts and disputes were not considered. The input data came from scientific contributions and online reports, so no real data were used. Further simulation models are needed to understand what other micro activities within the areas of order management, logistics and warehousing might be affected using BT. Furthermore, it would be interesting to assess through other simulation models what impacts the use of blockchain might have on supply chain relationships and time performance in other sectors such as high-tech, automotive, pharmaceutical or manufacturing.

Chapter V – A cost analysis of integrating blockchain technology, RFID and IoT within the supply chain

V.1. Introduction

The previous chapters discussed the advantages and importance of integrating cutting-edge technologies based on data acquisition in order to facilitate SCM. One of the reasons for the low adoption of these technologies, especially blockchain, is their high implementation costs as widely discussed theoretically in the literature (Cole et al., 2019; Gopalakrishnan et al., 2021; Venkatesh et al., 2020; Vu et al., 2021). This chapter aims to demonstrate how the integration of RFID, IoT, blockchain and smart contracts could impact on SCM costs. In order to propose a benchmark, again two models of the cheese supply chain were proposed using the same actors (i.e., as-is and to-be scenarios). The Time-Driven Activity-based Costing (TDABC) method was applied to conduct this research (Adıgüzel and Floros, 2020; Kaplan and Anderson, 2007). The method involves allocating costs directly to specific departments considering the time to carry out each activity. Furthermore, three different procurement policies for retailers Economic Order Quantity (EOQ), Lot for Lot (L4L) and Period Order Quantity (POQ) were considered in both scenarios. Finally, the cost analysis includes the economic assessment of non-compliant cheese wheels.

The aim of the chapter is to evaluate the economic feasibility of implementing technologies within the supply chain. In particular, this study provides:

- an economic assessment for each department;
- an economic assessment for each supply chain member;
- an economic assessment of the entire supply chain;
- an economic assessment of the effect of different supply policies;
- an economic assessment of non-compliant products.

The TDABC method, the description of the different scenarios and the dynamics for each actor in the network are shown in section V.2. The cost analysis of each department and the cost model is described in section V.3. The results of the economic feasibility are presented in section V.4. Finally, discussions close the chapter.

V.2. Research method

V.2.1. Time-driven ABC

The steps of the TDABC are presented in figure V.1. The first step is to recognise the resource pool performing the activities for each department. Once the time and costs of each resource pool have been identified, the costs are divided by the time capacity of each resource pool. Then, the unit cost is multiplied by the time of each activity (Kaplan and Anderson, 2004). The total cost is the sum of the costs for each activity. The time consumed for each activity is a function of several factors named "time-drivers". In particular:

- β_0 is the constant amount of time for the specific activity;
- $\beta_{1,2,\ldots,}$ p is the time consumption per unit of time driver 1, 2,… p;
- $X_{1,\ldots,k}$ represent the time drivers:
- p is the number of time factors that determine the time needed to carry out the activity j.

This methodology reduces complexity and facilitates updating for measurement (Everaert et al., 2008).

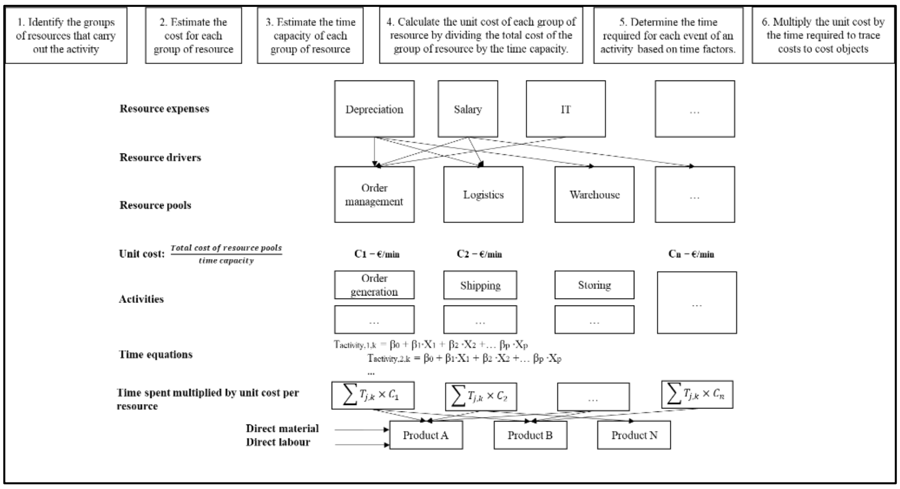


Figure V.1. *TDABC adapted from Kaplan and Anderson (2007)*

V.2.2. Scenarios description

The actors and the product considered in the simulation are the same as in *Chapter IV*. In this case, export is planned for France, which is one of the biggest importers of Italian cheese. This simulation does not include the warehouse for the 3PL and the logistics for the three retailers. The demand for cheese wheels is monthly based on a triangular distribution with a mode value of six cheese wheels for the three retailers. The warehouses were preloaded to eliminate the warm-up phase and meet one month's demand. In spite of the simulation models presented in the previous chapters, this is characterised by different procurement policies for the three retailers EOQ, POQ and L4L. For upstream actors, there are no specific supply policies as they could supply other products and actors and therefore the complexity of the simulation would be high. For EOQ policy, stock monitoring is updated daily. If the stock quantity is below the reorder point (ROP), the retailer generates a new order. For L4L policy, retailers are restocked every month according to the cheese wheels consumed. For POQ policy, cheese wheels are reordered every two months according to the quantity to be covered in the established period. In order to account non-compliant cheeses due to accidental problems (i.e., change in environmental conditions, opening of the seal, accidental damage), probability of occurrence was considered based on a triangular distribution in which the minimum value is 0.03, the maximum value is 0.07 and the mean value is 0.05. The cost analysis for non-compliant products depends on three factors: number of unfilled orders, number of non-compliant cheese wheels and managing time for non-compliant products (Appendix A). The simulation is based on a cost analysis for the first and fifth years. The simulation model is presented in figure V.2. In this case, each actor has its own database and does not share it with the other actors in the network. Moreover, communication takes place via e-mail, telephone calls and the use of Excel.

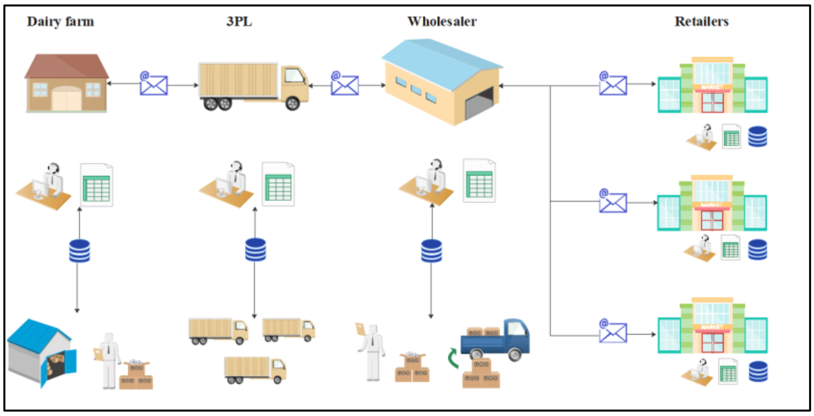


Figure V.2. *As-is scenario.*

Figure V.3 presents the conceptual model of the to-be scenario integrating the different technologies. In spite of the as-is scenario, BT operates as a common and shared platform for the actors involved, ensuring transparency and visibility to the entire chain.

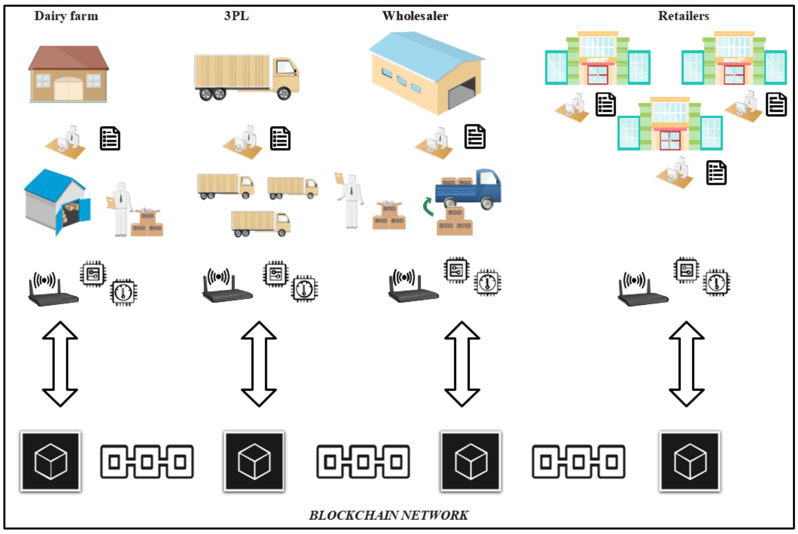


Figure V.3. *To-be scenario.*

5.2.3. Blockchain implementation cost

The to-be scenario involves the use of smart contracts, blockchain, IoT and RFID in the cheese supply chain. Costs were detected from the analysis of scientific articles (Gopalakrishnan et al., 2021; Longo et al., 2019; Omar et al., 2020; Venkatesh et al., 2020). Blockchain costs are summarised in Tables V.1. They refer to a private platform with a website and mobile application for supply chain members (Leewayhertz, 2022; Merehead, 2022a).

Table V.1. *Blockchain cost.*

Phases of blockchain implementation	**Description**	**Cost**
Planning (10%)	Application domain analysis, requirements analysis and feasibility analyses are carried out.	16,706 €
Design (15%)	Blockchain architecture is identified based on functional requirements. It is categorized into functional design and detailed design. A white paper is produced explaining the blockchain architecture and having functional specifications defined.	25,059€
Development (50%)	The code is written. Sites, smart contracts and web app are created that allow easy and faster interaction between users.	83,531 €
Assurance (25%)	It includes activities to ensure the architecture security.	41,766 €
Blockchain cost		**167,062 €**
Maintenance cost (10%)	It includes fixes or improvements.	**16,706 €**
Total Cost for Blockchain		**183,768 €**

In the to-be scenario, transport, storage and delivery data are collected by RFID and IoT and securely recorded in blockchain. In particular, data communication is performed using a single-board computer installed in the 3PL and wholesaler's trucks and in the warehouse shelves of each actor. RFIDs are applied to each pallet shipped and are affixed to each cheese wheel in the warehouse. In addition, smart contracts have been implemented that include the following functions:

- *Sendproduct ()*: it provides details on the cheese wheels sent;
- *Sign ()*: it verifies the signing phase;
- *Temperature ()*: it records the temperature variation of the cheese wheels outside the established parameters;
- *Maintenance ()* it stores additional product information for the warehouse.

The cost of a smart contract of medium complexity is € 4,250. The cost of the smart contract is referred to the sender who employs it (Merehead, 2022b). Each actor defines its own smart contract for direct communication with the specific supply chain member. The price of each transaction and the associated gas consumption is presented in Table V.2 (Etherscan, 2022).

Table V.2. *Transaction costs.*

Instruction	Gas [ETH]	Price[€/transaction]
SendProduct()	292.435	0.72
Sign()	792.936	1.96
Temperature()	25.796	0.06
Mainteinance ()	112.607	0.28

V.2.3. Dairy farm

The steps considered in this simulation model are the same as in *Chapter IV*. In the as-is scenario, the cheese wheels are stored in the warehouse. After the order has been placed by the wholesaler, an order clerk checks stock availability. If there are cheese wheels in the warehouse, he assigns the tasks of picking, checking and packing to a warehouse worker. In the meanwhile, he applies a delivery to the 3PL for France. Finally, when the truck arrives at the dairy farm location, the goods are loaded inside, and the documentation is signed. In this case, thermoregulators with a range of 20 metres and handheld devices for each warehouse worker are used.

The to-be scenario involves the same material flow. In this case, the time of order management is reduced by the use of smart contracts. According to scientific literature, the time to handle order management activities was halved compared to the as-is scenario (Ellram, 1995; Lohmer et al., 2020; Longo et al., 2019; Martínez-Navarro et al., 2019; Martinez et al., 2019; Zhang and Yi, 2008). In this case, a single common platform is used, data between the real and virtual warehouses are aligned and there is complete visibility of transactions between the network actors. Table V.3 presents the dairy farm's resource pool, activities, time and costs. The cost of the resource includes the total labour cost including taxes. Table V.4. shows the equipment costs of the dairy farm. In this scenario, the temperature controller and handhelds are replaced by RFID, single board computers, IoT, blockchain and smart contracts.

Table V.3. *Dairy farm' resource pool, activities, time and costs.*

Department unit	Resources	#	Activities	Time – as-is	Time – to-be	Cost [€/month]
Warehouse	Warehouse worker	3	Storing	TD (8 min; 10 min; 12 min)		3,000
Order management	Order clerk	1	Order receipt	ND (13 min; 3 min)	ND (6.5 min; 1.5 min)	4,400
			Order processing	ND (13 min; 3 min)	ND (6.5 min; 1.5 min)	
			Order generation	ND (10 min; 2 min)	ND (5 min; 1 min)	
Logistics	Warehouse worker	3	Picking	ND (8 min; 2 min)		3,000
			Checking	ND (4.5 min; 1 min)		
		3	Packing	ND (7.5 min; 1.5 min)		3,000
		3	Signing	ND (5 min; 1 min)	ND (5 sec; 0.1 sec)	3,000

Table V.4. *Dairy farm's equipment.*

Equipment	#	Cost	Area allocation	Years of depreciation	As-is	To-be
Stacker crane	3	35,000 €/unit	Warehouse	10	✓	✓
Forklift	1	4,540 €/unit	Warehouse	5	✓	✓
Shelving module	2,052	1.60 €/unit	Warehouse	10	✓	✓
Box	20	2.96 €/unit	Logistics	-	✓	✓
Pallet	10	30.75 €/unit	Logistics	-	✓	✓
ERP Software	1	18,000 €/unit	Order management	3	✓	✓
Thermoregulator	18	285 €/unit	Warehouse	2	✓	✗
Handheld	3	524 €/unit	Warehouse	2	✓	✗
Blockchain technology	1	30,628 €/actor	Order management, Warehouse & Logistics	3	✗	✓
Temperature sensor	18	10 €/item	Warehouse	3	✗	✓
Smart Contract	1	4,250 €/item	Order management	3	✗	✓
Single-board computer	18	200€/item	Warehouse	3	✗	✓
IoT-Blockchain infrastructure	1	1200 €/item	Warehouse	3	✗	✓
RFID	200	0.20 €/item	Warehouse	-	✗	✓

V.2.4. 3PL

3PL receives the order request from the dairy farm. Once the dairy farm's batch is ready, a driver drives to the dairy farm, loads the pallets inside the truck and, then the warehouse worker signs the shipping documents. In the to-be scenario, smart contracts regulate relations between multiple actors using passphrases. In addition, documents are fully digitalized. Tables V.5 and V.6 illustrate the resource pool activities, time and costs and equipment costs of the 3PL, respectively.

V.2.5. Wholesaler

Once the goods arrive at the wholesaler in France, a warehouse worker unloads the cheese wheels, checks for damage, signs the documentation and deposits them in the warehouse. Once the retailers' order request arrives, an order clerk checks the available cheese wheels in stock. If they are available, he assigns a warehouse worker to complete the activities of picking, checking, packing and loading inside the truck. To optimise the load, the multidrop strategy is applied to supply RA, RB and RC. The to-be scenario involves the integration of different technologies in all areas of SCM: warehouse, logistics and order management. Table V.7 shows the wholesaler's resource pools, activities, time and costs. Table V.8. presents the wholesaler's equipment costs. In this case, the size of the wholesaler's truck is smaller than 3PL’s truck.

Table V.5. *3PL's resource pool, activities, time and costs.*

Department unit	Resources	#	Activities	Time – as-is	Time – to-be	Cost [€/month]
Order management	Order clerk	1	Order receipt	ND (13 min; 3 min)	ND (6.5 min; 1.5 min)	4,400
			Order processing	ND (13 min; 3 min)	ND (6.5 min; 1.5 min)	
Logistics	Truck driver	1	Shipping	ND (11 h; 40 min)		4,200

Table V.6. *3PL's equipment.*

Equipment	#	Cost	Area allocation	Years of depreciation	As – Is	To – Be
ERP Software	1	18,000 €/unit	Order management	3	✓	✓
Truck	1	113,000 €/unit	Logistics	10	✓	✓
Fuel cost		1.04 €/lt	Logistics	-	✓	✓
Maintenance cost		0.22 €/km	Logistics	-	✓	✓
Toll cost		42€	Logistics	-	✓	✓
Blockchain technology	1	30,628 €/actor	Order management & Logistics	3	×	✓
Temperature sensor	1	10 €/item	Logistics	3	×	✓
Smart Contract	1	4250 €/item	Order management	3	×	✓
Single-board computer	1	200€/item	Logistics	3	×	✓
IoT-Blockchain infrastructure	1	1200 €/item	Logistics	3	×	✓

Table V.7. *Wholesaler's resource pool, activities, time and costs.*

Department unit	Resources	#	Activities	Time – as-is	Time – to-be	Cost [€/month]
Warehouse	Warehouse worker	2	Checking pallet	ND (10 min; 1 min)		4,000
			Truck unloading	ND (25 min; 2 min)		
			Signing documentation	ND (5 min; 1 min)	ND (5 sec; 0.1 sec)	
			Storing	TD (20 min, 25 min; 30 min)		
Order management	Order clerk	1	Order receipt	ND (13 min; 3 min)	ND (6.5 min; 1.5 min)	6,400
			Order processing	ND (13 min; 3 min)	ND (6.5 min; 1.5 min)	
			Order generation	ND (10 min; 2 min)	ND (5 min; 1 min)	
Logistics	Warehouse worker	2	Picking	ND (8 min; 2 min)		4,000
			Checking	ND (4.5 min; 1 min)		
		2	Packing	ND (7.5 min; 1.5 min)		
			Signing	ND (5 min; 1 min)	ND (5 sec; 0.1 sec)	
	Truck Driver	1	Shipping truck for retailer A – B – C	ND (1 h and 27 min; 17 min) **(RA)** ND (1 h and 48 min; 20 min) **(RB)** ND (42 min; 8 min) **(RC)**		5,600

Table V.8. *Wholesaler's equipment.*

Equipment	#	Cost	Area allocation	Years of depreciation	As – Is	To – Be
Stacker crane	1	35,000 €/unit	Warehouse	10	✓	✓
Forklift	1	4,540 €/unit	Warehouse	5	✓	✓
Shelving module	2,052	1.60 €/unit	Warehouse	10	✓	✓
Truck	1	17,500 €/unit	Logistics	10	✓	✓
Thermoregulator	18	285 €/unit	Warehouse	2	✓	✗
Handheld	2	524 €/unit	Warehouse	2	✓	✗
Box	20	2.96 €/unit	Logistics	-	✓	✓
Pallet	3	30.75 €/unit	Logistics	-	✓	✓
ERP Software	1	18,000 €/unit	Order management	3	✓	✓
Fuel cost		1.211 €/lt	Logistics		✓	✓
Maintenance cost		0.22 €/km	Logistics		✓	✓
Toll cost		50€/route	Logistics		✓	✓
Blockchain technology	1	30,628 €/actor	Order management, Warehouse and Logistics	3	✗	✓
Temperature sensor	19	10 €/item	Warehouse& Shipping	3	✗	✓
Smart Contract	1	4,250 €/item	Order management	3	✗	✓
Single-board computer	19	200€/item	Warehouse & Logistics	3	✗	✓
IoT-Blockchain infrastructure	2	1,200 €/item	Warehouse & Logistics	3	✗	✓
RFID	54	0.20 €/item	Logistics	-	✗	✓

V.2.6. Retailer

Three procurement policies were considered for the three retailers: EOQ, POQ, L4L. There are two cost factors in EOQ: average order cost and average inventory maintenance cost. The formula used is the following (Shapiro and Wagner, 2009):

$$EOQ = \sqrt{\frac{2*D*Co}{t*p}} \tag{1}$$

In which:

D = demand in a period considered;

Co = cost of a single order;

t = product maintenance rate in stock;

p = price of a single product.

After determining the EOQ value, it is necessary to understand how often to place orders: the model used the ROP. The ROP indicates the inventory level in which a new purchase order should be issued, and it is calculated by multiplying the demand by the lead time. In addition to this value is also added the safety stock, necessary to avoid delays or interruptions (2) (Jiraruttrakul et al., 2017).

$$ROP = D * Lead\ Time + SS \tag{2}$$

The following formula calculates the safety stock (3):

$$SS = z * \ \sigma_{dLT} \tag{3}$$

In particular, σ_{dLT} is the standard deviation of demand during the lead time while z indicates the normal standard (this value has been assumed of 95%). Table V.9 shows the data input for the EOQ scenario.

Table V.9. *Data input for EOQ policy.*

Variable	Unit
C	11.10 €/order
T	1%
p	418 €/cheese wheels
σdLT	20%
z	1,65
D	6 cheese wheels

For L4L the number of orders is equal to 12 (Grubbström and Thuy Huynh, 2006). For POQ the number of order is set every two months (Sánchez et al., 2001). Tables V.10 and V.11 show the retailers' resources and equipment costs respectively.

Table V.10. *Retailer's resource pool, activities, time and costs.*

Department unit	Resources	#	Activities	Time – as-is	Time – to-be	Cost [€/month]
Order management	Order clerk	1	Order generation	ND (10 min; 30 sec)	ND (5 min; 15 sec)	6,400
Warehouse	Worker	1	Storing	TD (8 min; 10 min; 12 min)		4,000
			Cutting	ND (2.5 min; 0.5 min)		

Table V.11. *Retailer's equipment.*

Equipment	#	Cost [€/unit]	Activity allocation	Years of depreciation	1° scenario	2° scenario
Shelving Module	513	1.67	Warehouse	10	✓	✓
Forklift	1	4,540	Warehouse	5	✓	✓
ERP	1	18,000	Order management	3	✓	✓
Thermoregulator	18	285	Warehouse	2	✓	×
Handheld	2	524	Warehouse	2	✓	×
Blockchain	1	30,628	Order management & Warehouse	3	×	✓
Temperature sensor	18	10	Warehouse	3	×	✓
Smart Contract	1	4250	Order management	3	×	✓
Single-board computer	18	200	Warehouse	3	×	✓
IoT infrastructure	1	1200	Warehouse	3	×	✓

V.3. Cost analysis

The TDABC method identifies the resource pool for each department and evaluates the time capacity. Then, the cost of resources is evaluated, which includes the stacker crane, forklift, employee salary, ERP system, shelving module, thermoregulator, truck, smart contracts, IoT infrastructure, blockchain and single board computer. For each department, the cost per minute is the total cost of the specific department considered divided by the total time capacity. For example, the cost per minute for the dairy farm's order management department is the sum of the employee costs and the depreciation rate of the ERP system divided by the time capacity (0.464 €/min). The departmental capacity cost is the sum of the unit costs multiplied by the time equation (Table V.12). Direct costs such as fuel, RFID labels, boxes and pallets are allocated directly to the specific area. The cost model only includes the analysis of cheese wheels destined for export to France. Supply chain members work five days a week, from 9 a.m. to 6 p.m.

V.3.1. Order management department costs

Tables V.12 illustrates for each actor the unit cost and time equations of both scenarios for the order management department. The time drivers assumed for this area are the number of orders (Table V.13). For to-be scenario, the costs for the *sendproduct()* transaction for each order sent are considered.

Table V.12. *Time equations for the order management department (as-is and to-be scenario).*

Actor	As-is [€/min] (C_{om})	To-be [€/min] (C_{om})	Time equation (T_{om})
Dairy farm	0.464	0.506	Order receipt and processing * [Number of wholesaler's order] + Order generation * [Number of 3PL's order] + Order generation * [Number of milk supplier's order]
3PL	0.464	0.506	Order receipt and processing * [Number of dairy farm's order]
Wholesaler	0.653	0.695	Order receipt and processing * [Number of retailers' order] + Order generation * [Number of dairy farm's order]
Retailer	0.653	0.695	Order generation * [Number of retailer's order]

Table V.13. *Number of orders for each actor.*

Actor	Description	Unit
Dairy farm	Orders for milk supplier	305 orders/year
3PL	Shipping for dairy farm	3 orders/year
Wholesaler	Orders for dairy farm	3 orders/year
Retailer	Orders with EOQ policy	4 orders/year
	Orders with L4L policy	12 orders/year
	Number of retailer orders with POQ policy	6 orders/year

V.3.2. Logistics department costs

Table V.14 defines for each actor the unit cost and time equations of both scenarios for the logistics department. The time drivers assumed for this area are the number of shipments. For to-be scenario, *sign()* transaction cost for each shipping are considered.

Table V.14. *Time equations for the logistics department unit.*

Actor	As-is [€/min] (Cl_{og})	To-be [€/min] (Cl_{og})	Time equation (Tl_{og})
Dairy farm	0.121	0.126	[Batch preparation + checking + loading + signing] * [Number of shipments]
3PL	0.404	0.433	[Journey + signing] * [Number of shipments]
Wholesaler	0.131	0.230	[Batch preparation + checking + loading + journey + signing] * [Number of shipments]

The cost of the boxes is allocated directly to the cheese wheels. For the to-be scenario, the single RFID cost per box is added. In addition, the dairy farm pays a 3PL rate of 10% on the total transportation costs. For the logistics cost, the cost of fuel, tolls, maintenance and insurance was taken into account. The load factor and travelled kilometres were evaluated. Table V.15 shows the variables considered.

Table V.15. *Transportation costs.*

Actor	**Km**	**Load Factor (LF) [lt/km]**	**Fuel Cost (FC) [€/lt]**	**Formula**
3PL	900	LF0% - 0.226	1.037	900 x LF100% x FC +
		LF100% - 0.360		900 x LF0% x FC
Wholesaler	168 (W->RA)	LF100% - 0.360	1.211	168 x LF100% x FC +
	67.2 (RA->RB)	LF66% - 0.288		67.2 x LF80% x FC +
	44.8 (RB->RC)	LF33% - 0.252		44.8 x LF60% x FC +
	232 (RC->W)	LF0% - 0.226		232 x LF0% x FC

The cost of maintenance depends on the kilometres driven. The toll cost for Italy is 42 €/trip and for France 50 €/trip. The cost of insurance for trucks has an insurance rate of 0.6%.

V.3.3. Warehouse department costs

The maximum capacity for the dairy farm and wholesaler was set at 20,524 cheese wheels, while a maximum capacity of 5,131 cheese wheels of the retailers. The time drivers for this area are the number of cheese wheels. Table V.16 shows the unit cost and the time equations for each actor for the warehouse. The cost of one wheel of cheese is € 418.00 (Parmigiano Reggiano, 2022).

Table V.16. *Time equations for the warehouse department unit.*

Actor	**As-is [€/min] (C_{wh})**	**To-be [€/min] (C_{wh})**	**Time equation (T_{wh})**
Dairy farm	0.126	0.130	Storing * [Cheese wheels]
Wholesaler	0.113	0.175	[Checking + unloading + storing] * [Cheese wheels]
Retailer	0.163	0.338	[Storing + cutting + packing] * [Cheese wheels]

V.3.4. Cost analysis model

The following Total Costs were identified.

Total Cost for Order Management (TC_{om}) (4):

$$TC_{om} = \sum(C_{om} \times T_{om}) + [C_{sendproduct()} \times N.orders]_{to-be} \qquad (4)$$

For the to-be scenario:

- $C_{sendproduct()}$= cost of *sendproduct()* transactions for to-be scenario.

Total Cost for Logistics *(TC_{log})* (5):

$$TC_{log} = \sum(C_{log} \times T_{log} + C_{log,packing} \times No.cheese\ wheels + fuel \times N.shipping + toll \times N.shipping) + (Maintenance \times Km) + Insurance + [C_{signproduct()} \times N.of\ shippings]_{to-be} \qquad (5)$$

Where:

- $Maintenance = 0.22 \left[\frac{€}{km}\right] \times km\ travelled$;
- $Insurance = TC_{log} \times interest\ rate$ (0.60%);
- $C_{signproduct()}$ = cost of *sign()* transaction for to-be scenario.

Total Cost for Warehouse *(TC_{wh})* (6):

$$TC_{wh} = \sum C_{wh} \times T_{wh} + Inventory\ maintenance\ cost \times N.cheese\ wheels + N.unfilled\ cheese\ wheels \times Cheese\ wheel\ cost \qquad (6)$$

Where:

- $Inventory\ maintenance\ cost = Cheese\ wheel\ cost \times Capacity\ warehouse \times Annual\ Interest\ Rate\ (10\%) \times No.export\ cheese\ wheels$

To evaluate the costs for each actor, a Total Supply Chain Cost *(TSCC)* (7) was considered, defined as:

$$TSCC = TC_{om} + TC_{log} + TC_{wh} \qquad (7)$$

In addition, the Total Cost for the Non-Compliant Products *(TCncp)* (8) for the three retailers was considered, defined as:

$$TC_{ncp} = \text{Cheese wheel cost} \times T_{ncp} \times N_{ncp} \times \left[C_{mainteinance()} + C_{temperature()}\right]_{to-be} \quad (8)$$

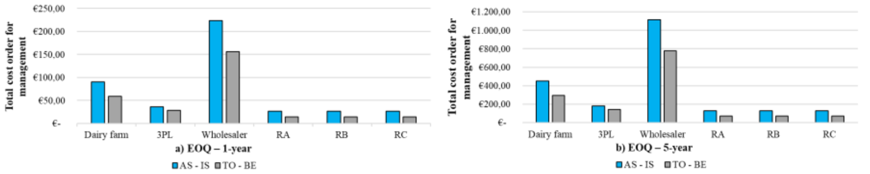
Where:

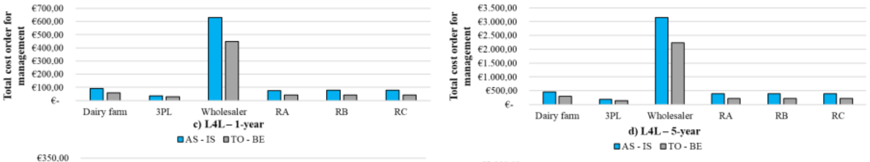
- T_{ncp} is the time for managing a non-compliant products;
- N_{ncp} is the number of non-compliant products;
- $C_{mainteinance()}$ = cost of *maintenance()* transactions for to-be scenario;
- $C_{temperature()}$ = cost of *temperature()* transactions for to-be scenario.

V.4. Total cost

V.4.1. Total cost for order management

Figure V.4 shows the graphs of each actor in the first and fifth year for order management. Although the unit cost per minute in the to-be scenario is higher than in the as-is scenario, the reduced time allows for a cost reduction. The time reduction is based on the automation of activities through the integration of smart contracts.





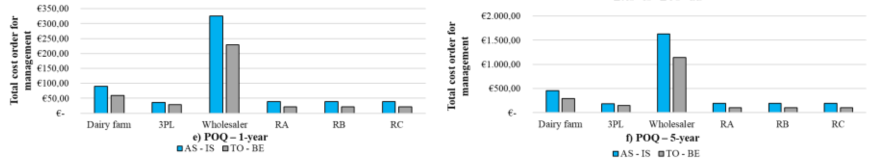


Figure V.4. *Total cost for order management.*

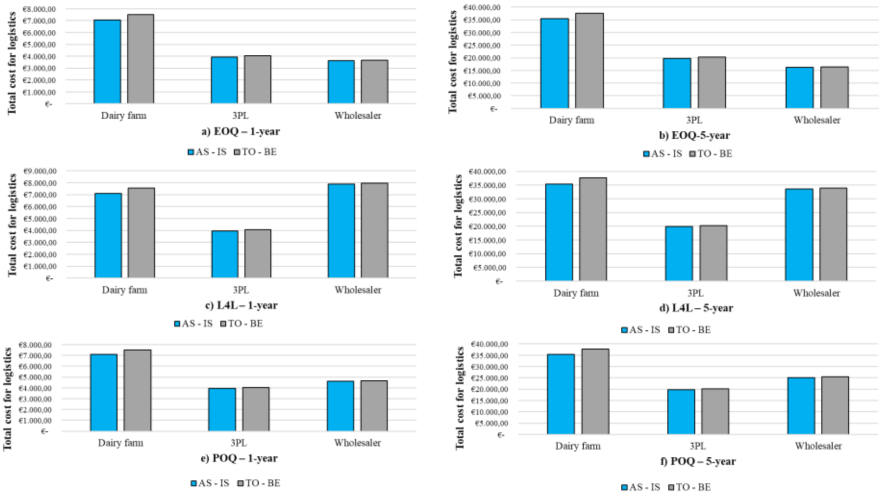
Table V.17 shows the total cost for order management for each actor divided by the different procurement policies at first and fifth. The costs for the dairy farm, 3PL and wholesaler are almost the same between the two scenarios as the procurement policies do not change. The lowest costs for retailers are associated with the scenario in which the EOQ policy is adopted. Interestingly, the time reduction for each department, even in the absence of a procurement policy, leads to a cost reduction. Specifically, the cost reduction is 35%, 21%, 30% and 47% for the dairy farm, 3PL, wholesaler and the three retailers respectively.

Table V.17. *Cumulative costs in the 1st and 5th year related to the orders management for each actor and procurement policies.*

EOQ						
	1° year			**5° year**		
	AS - IS	**TO - BE**	**Δ%**	**AS - IS**	**TO - BE**	**Δ%**
Dairy farm	90.55 €	59.30 €	35%	452.75 €	294.29 €	35%
3PL	36.19 €	28.55 €	21%	180.97 €	142.76 €	21%
Wholesaler	223.47 €	155.92 €	30%	1,117.33 €	779.60 €	30%
RA	26.14 €	13.90 €	47%	130.68 €	69.52 €	47%
RB	26.14 €	13.90 €	47%	130.68 €	69.52 €	47%
RC	26.14 €	13.90 €	47%	130.68 €	69.52 €	47%
Total	**428.62 €**	**285.49 €**	**33%**	**2,143.09 €**	**1,425.20 €**	**33%**
L4L						
Dairy farm	90.55 €	59.30 €	35%	452.75 €	294.29 €	35%
3PL	36.19 €	28.55 €	21%	180.97 €	142.76 €	21%
Wholesaler	631.19 €	446.91 €	29%	3,155.97 €	2.234.54 €	29%
RA	78.41 €	41.71 €	47%	392.05 €	208.55 €	47%
RB	78.41 €	41.71 €	47%	392.05 €	208.55 €	47%
RC	78.41 €	41.71 €	47%	392.05 €	208.55 €	47%
Total	**993.16 €**	**659.89 €**	**33%**	**4,965.81 €**	**3,297.23 €**	**33%**
POQ						
Dairy farm	90.55 €	59.30 €	35%	452.75 €	294.29 €	35%
3PL	36.19 €	28.55 €	21%	180.97 €	142.76 €	21%
Wholesaler	325.40 €	228.67 €	30%	1,626.99 €	1,143.34 €	30%
RA	39.20 €	20.85 €	47%	196.02 €	104.27 €	47%
RB	39.20 €	20.85 €	47%	196.02 €	104.27 €	47%
RC	39.20 €	20.85 €	47%	196.02 €	104.27 €	47%
Total	**569.75 €**	**379.09 €**	**33%**	**2,848.77 €**	**1,893.20 €**	**33%**

V.4.2. Total cost for logistics

Figure V.5 presents the total cost for logistics of each actor in the first and fifth years. The implementation of technologies in the logistics area leads to additional costs for supply chain members. The unit cost per minute in the to-be scenario is increased for all actors, however the time needed to perform the various activities is the same, except for signing documentation.



a) EOQ – 1-year

b) EOQ-5-year

c) L4L – 1-year

d) L4L – 5-year

e) POQ – 1-year

f) POQ – 5-year

Figure V.5. *Total cost for logistics.*

Table V.18 presents the total cost for logistics for each participant. Different procurement policies influence the wholesaler's costs. The EOQ policy reduces costs as the number of shipments is lower. The costs for the to-be scenario increase by 6%, 2% and 1% for the dairy farm, the 3PL and the wholesaler respectively. The costs of the technological infrastructure within the truck and the warehouse imply additional costs.

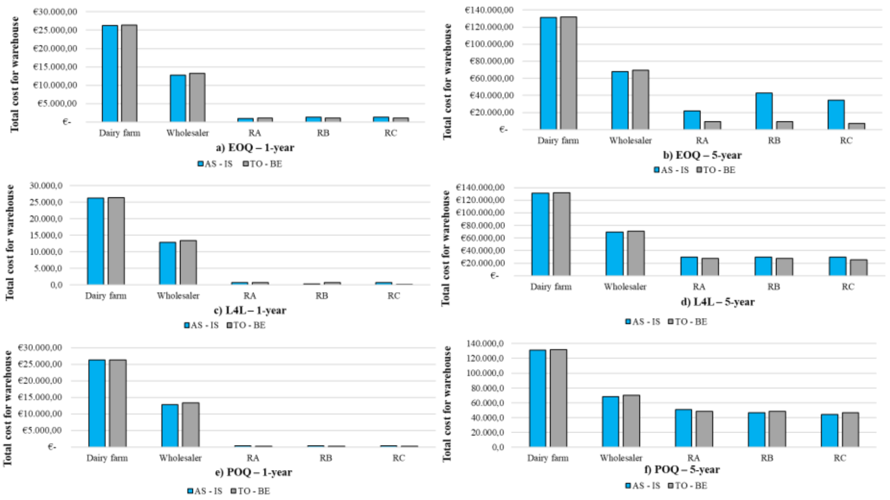
Table V.18. *Cumulative costs in the 1st and 5th year related to the logistics for each actor and the different procurement policies.*

EOQ						
	1° year			5° year		
	AS - IS	TO - BE	Δ%	AS - IS	TO - BE	Δ%
Dairy farm	7,069.51 €	7,507.91 €	-6%	35,435.99 €	37,627.44 €	-6%
3PL	3,948.99 €	4,026.40 €	-2%	19,825.33 €	20,211.92 €	-2%
Wholesaler	3,615.37 €	3,654.73 €	-1%	16,223.03 €	16,419.82 €	-1%
Total	**14,633.87 €**	**15,189.04 €**	**-4%**	**71,484.35 €**	**74,259.18 €**	**-4%**
L4L						
Dairy farm	7,087.20 €	7,525.49 €	-6%	35,435.99 €	37,627.44 €	-6%
3PL	3,965.07 €	4,042.38 €	-2%	19,825.33 €	20,211.92 €	-2%
Wholesaler	7,866.84 €	7,951.55 €	-1%	33,512.10 €	33,935.60 €	-1%
Total	**18,919.11 €**	**19,519.42 €**	**-4%**	**88,773.42 €**	**91,774.96 €**	**-4%**
POQ						
Dairy farm	7,087.20 €	7,525.49 €	-6%	35,435.99 €	37,627.44 €	-6%

3PL	3,965.07 €	4,042.38 €	-2%	19,825.33 €	20,211.92 €	-2%
Wholesaler	4,609.40 €	4,655.49 €	-1%	25,136.86 €	25,560.38 €	-1%
Total	**15,661.66 €**	**16,223.36 €**	**-4%**	**80,398.18 €**	**83,399.74 €**	**-4%**

V.4.3. Total cost for warehouse

Figure V.6 shows the total cost for warehouse of each participant. The implementation of technologies within the warehouse brings additional costs to the dairy farm and the wholesaler. Indeed, the addition of other technological infrastructures involves an increase in costs. The unit cost per minute for the to-be scenario has increased for all the participants and the timing of the activities is the same for both the scenarios. The costs of unsold cheeses were also considered for retailers as they were not in stock (see Appendix A). Retailers could have unfilled orders in the as-is scenario because they have no visibility on inventory that led to not being reactive to meet demand. The graphs illustrate that with the POQ policy there is an increase in costs. The L4L policy based on monthly supply mitigates the issue of unsold cheeses. The EOQ policy allows to avoid misalignments in the warehouse thanks to the visibility of the inventory on the blockchain. Both the dairy farm and the wholesaler do not employ any procurement policies, and this generates an inevitable increase in costs for the to-be scenario.



a) EOQ – 1-year

b) EOQ – 5-year

c) L4L – 1-year

d) L4L – 5-year

e) POQ – 1-year

f) POQ – 5-year

Figure V.6. *Total cost for warehouse.*

Figure V.6 presents the total cost for the warehouse of each participant. The addition of other technological infrastructures leads to an increase in costs for all actors, however, the time for material flow management has remained unchanged. The unit cost per minute for the to-be scenario increased for all participants compared to the as-is scenario. For retailers, the costs of unsold cheeses, as they are not in stock, were also considered (see Appendix A). In the as-is scenario where each participant has their own database, it is difficult to plan reorders and be reactive to meet demand. Both POQ and L4L policies lead to increased costs. Actors who do not adopt specific procurement policies suffer an inevitable cost increase for the to-be scenario.

Table V.19. *Cumulative costs in the 1st and 5th year related to the warehouse for each actor and different procurement policies.*

EOQ						
	1° year			**5° year**		
	AS - IS	**TO - BE**	**Δ%**	**AS - IS**	**TO - BE**	**Δ%**
Dairy farm	26,276.04 €	26,343.87 €	0%	131,378.55 €	131,718.13 €	0%
Wholesaler	12,828.27 €	13,300.55 €	-4%	67,768.56 €	69,785.51 €	-4%
RA	996.46 €	1,040.71 €	-4%	21,708.45 €	9,318.47 €	57%
RB	1,370.06 €	1,040.71 €	24%	42,608.45 €	9,273.78 €	78%
RC	1,388.71 €	1,040.71 €	25%	34,217.37 €	7,228.47 €	79%
Total	**42,859.54 €**	**42,766.56 €**	**0%**	**297,681.39 €**	**227,324.35 €**	**24%**
L4L						
Dairy farm	26,276.04 €	26,343.87 €	0%	131,378.55 €	131,718.13 €	0%
Wholesaler	12,895.31 €	13,354.39 €	-4%	69,444.53 €	71,131.67 €	-2%
RA	610.01 €	590.92 €	3%	29,687.17 €	27,498.31 €	7%
RB	192.01 €	590.92 €	-208%	29,687.17 €	27,498.31 €	7%
RC	612.74 €	172.98 €	72%	29,689.89 €	25,408.37 €	14%
Total	**40,586.12 €**	**41,053.09 €**	**-1%**	**289,887.31 €**	**283,254.77 €**	**2%**
POQ						
Dairy farm	26,276.04 €	26,343.87 €	0%	131,378.55 €	131,718.13 €	0%
Wholesaler	12,845.03 €	13,314.01 €	-4%	68,187.55 €	70,122.05 €	-4%
RA	295.85 €	287.57 €	3%	50,573.42 €	48,435.27 €	4%
RB	295.85 €	287.57 €	3%	46,393.42 €	48,435.27 €	-4%
RC	301.21 €	287.60 €	5%	44,308.78 €	46,345.30 €	-5%
Total	**40,013.97 €**	**40,520.63 €**	**-1%**	**340,841.73 €**	**345,056.01 €**	**-1%**

V.4.4. Total supply chain cost

Figure V.7 illustrates the total supply chain cost. The total cost of the supply chain is the sum of the total cost for order management, logistics and warehouse. In general, the costs of the to-be scenario are higher than the as-is scenario.

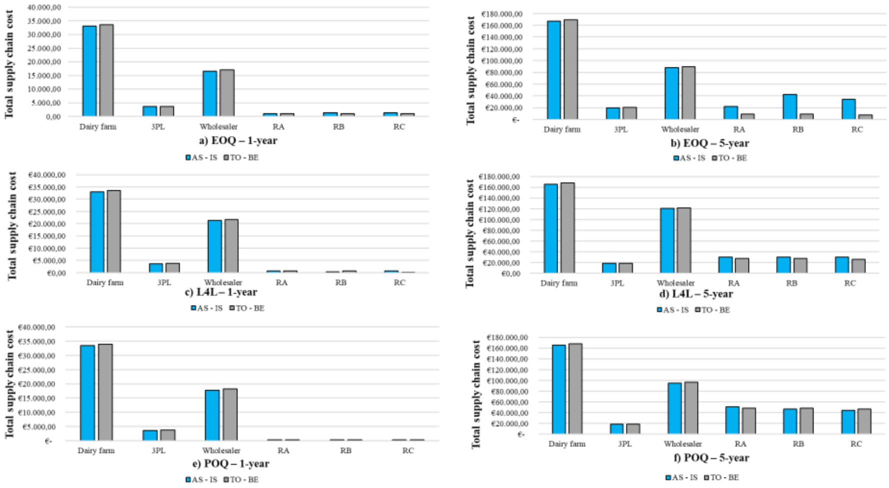

a) EOQ – 1-year
b) EOQ – 5-year
c) L4L – 1-year
d) L4L – 5-year
e) POQ – 1-year
f) POQ – 5-year

Figure V.7. *Total supply chain cost.*

Table V.20 shows the costs of supply chain members divided by the different procurement policies. The costs for dairy farm, 3PL and the wholesaler in the to-be scenario increase in the range of 1% to 3%. However, this variation is not significantly high. The cost reduction of retailers is balanced by the cost increase of upstream actors. In addition, adopting L4L and POQ policies leads to cost growth up to the fifth year.

Table V.20. *Cumulative costs in the 1st and 5th year related to the supply chain for each actor and different procurement policies.*

	EOQ					
	1° year			**5° year**		
	AS - IS	**TO - BE**	**Δ%**	**AS - IS**	**TO - BE**	**Δ%**
Dairy farm	33,082.42 €	33,559.51 €	-1%	167,267.29 €	169,551.99 €	-1%
3PL	3,663.65 €	3,735.34 €	-2%	20,006.30 €	20,354.68 €	-2%
Wholesaler	16,667.10 €	17,111.19 €	-3%	87,664.84 €	89,767.58 €	-2%
RA	1,008.77 €	1,054.62 €	-5%	21,770.0 €	9,387.98 €	57%
RB	1,396.20 €	1,054.62 €	24%	42,739.13 €	9,343.30 €	78%
RC	1,414.85 €	1,054.62 €	25%	34,348.05 €	7,297.98 €	79%
Total	**57,232.98 €**	**57,569.90 €**	**-1%**	**373,795.62 €**	**305,703.51 €**	**18%**
	L4L					
Dairy farm	33,082.42 €	33,559.51 €	-1%	165,410.43 €	167,706.21 €	-1%
3PL	3,663.65 €	3,735.34 €	-2%	18,318.25 €	18,676.70 €	-2%
Wholesaler	21,393.34 €	21,752.85 €	-2%	120,294.23 €	121,483.45 €	-1%
RA	646.95 €	632.63 €	2%	29,871.83 €	27,706.85 €	7%

RB	270.42 €	632.63 €	-134%	30,079.21 €	27,706.85 €	8%
RC	691.15 €	214.69 €	69%	30,081.94 €	25,616.91 €	15%
Total	**59,747.93 €**	**60,527.65 €**	**-1%**	**394,055.89 €**	**388,896.98 €**	**1%**
			POQ			
Dairy farm	33,082.42 €	33,559.51 €	-1%	165,410.43 €	167,706.21 €	-1%
3PL	3,663.65 €	3,735.34 €	-2%	18,318.25 €	18,676.70 €	-2%
Wholesaler	17,779.82 €	18,236.78 €	-3%	94,951.40 €	96,825.76 €	-2%
RA	314.31 €	308.43 €	2%	50,665.75 €	48,539.54 €	4%
RB	335.05 €	308.43 €	8%	46,589.45 €	48,539.54 €	-4%
RC	340.41 €	308.46 €	9%	44,504.81 €	46,449.57 €	-4%
Total	**55,515.67 €**	**56,456.94 €**	**-2%**	**420,440.09 €**	**426,737.33 €**	**-1%**

V.4.5. Total cost for non-compliant products

The EOQ policy reduces the costs of managing non-compliant cheese wheels by monitoring in real time and reordering stock quickly. In addition, the presence of smart contracts allows costs to be reduced by automating certain activities. At fifth year, the results are more balanced as non-compliant products are spread out over a longer time horizon as shown in figure V.8.

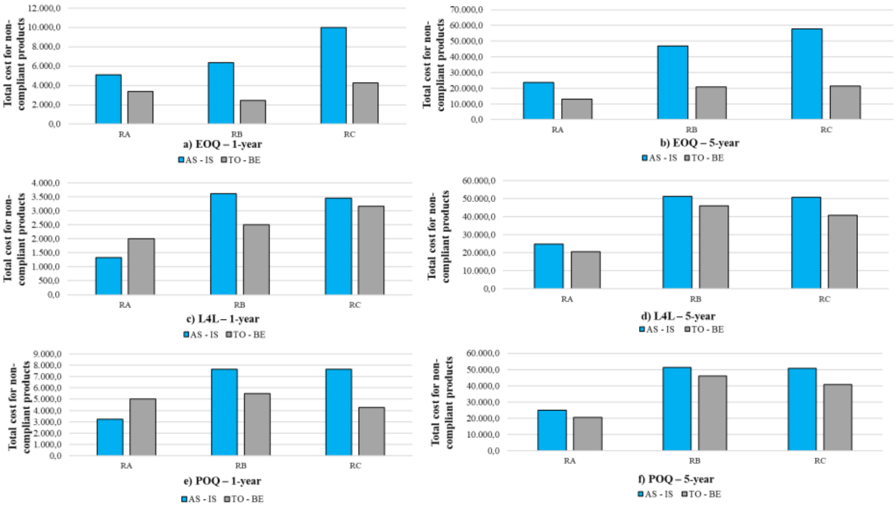


Figure V.8. *Total cost for non-compliant products for each retailer considering the different procurement policies.*

Table V.21 shows the costs of the three retailers for managing non-compliant products. The results clarify that in the 5-year of the to-be scenario there is a cost reduction ranging from 8% to 12% for L4L, while there is a cost reduction ranging from 10% to 20% for POQ. This cost reduction is less noticeable than for the EOQ policy, which reaches ranges from 34% to 62% in the first year and 45% to 63% in the fifth year.

Table V.21. *Cumulative costs in the 1st and 5th year related to the non-compliant products for each actor the different procurement policies.*

EOQ						
	1° year			**5° year**		
	AS - IS	**TO - BE**	**Δ%**	**AS - IS**	**TO - BE**	**Δ%**
RA	5,096.59 €	3,378.46 €	34%	23,544.03 €	12,985.00 €	45%
RB	6,351.14 €	2,419.14 €	62%	47,045.45 €	20,687.86 €	56%
RC	9,997.16 €	4,254.36 €	57%	57,865.91 €	21,271.79 €	63%
Total	**21,444.89 €**	**10,051.96 €**	**53%**	**128,455.40 €**	**54,944.64 €**	**57%**
L4L						
RA	1,329.55 €	2,002.05 €	-51%	7,977.27 €	6,987.56 €	12%
RB	3,606.82 €	2,502.56 €	31%	16,230.68 €	14,181.19 €	13%
RC	3,450.00 €	3,169.91 €	8%	14,662.50 €	13,472.13 €	8%
Total	**8,386.36 €**	**7,674.53 €**	**8%**	**38,870.45 €**	**34,640.88 €**	**11%**
POQ						
RA	3,213.07 €	5,005.13 €	-56%	24,799.72 €	20,598.00 €	17%
RB	7,644.89 €	5,505.64 €	28%	51,318.75 €	46,088.87 €	10%
RC	7,644.89 €	4,254.36 €	44%	50,652.27 €	40,708.36 €	20%
Total	**18,502.84 €**	**14,765.12 €**	**20%**	**126,770.74 €**	**107,395.23 €**	**15%**

V.5. Discussion

The chapter aims to investigate the economic feasibility of integrating IoT, RFID and blockchain in the different areas of SCM in order to carry out an overall economic assessment. The chapter offers different perspectives of analysis: a) an economic assessment for each department unit; b) an economic assessment for each supply chain member; c) an economic assessment of the entire supply chain; d) an economic assessment of the effect of different procurement policies; e) an economic assessment for non-compliant products. Considering the first point, the integration of technologies within the supply chain leads to an overall increase in costs per minute in each department. However, the total cost for order management is reduced as the activities have been automated by the technology infrastructure in the to-be scenario. For the logistics and warehousing area, there are additional costs based on the implementation of RFID on pallets and cheese wheels, the use of IoT infrastructure for data communication and, finally, the blockchain that allows data to be collected in one common, shared, secure and reliable platform.

Considering the costs of the two scenarios, they are not radically different. Indeed, order management activities offset the costs of the technological infrastructure in logistics and warehousing by balancing supply chain costs. The second point is related to the cost of implementation for each actor. In this case, retailers receive an economic benefit from the implementation of these technologies. The main reason is the use of specific procurement policies, especially when EOQ policy is employed. Indeed, upstream actors in the supply chain also suffer from a general increase in costs because they do not adopt specific procurement policies. However, adopting technologies in the warehouse of retailers is not cost-effective. The third point relates to an economic evaluation of the entire supply chain. Investment in new technologies can be considered worthy if other quality parameters that the technologies provide such as security, reliability, traceability, real-time communications, adoption of a single platform, and the highest responsiveness to market demand are taken into account. In this simulation scenario, transaction costs are considered negligible. They may no longer be negligible when there are more actors or products. In the to-be scenario, the total supply chain cost compared to the as-is scenario has a cost increase from 1% to 2%. Upstream actors are economically disadvantaged because they do not adopt procurement policies. However, retailers gain a greater economic benefit and rebalance the total supply chain costs. Furthermore, with the EOQ policy in the fifth year there is a cost reduction of 18%, for L4L of 1% while adopting the POQ policy there is a cost increase of 1%.

The fourth point clarifies for which procurement policies it is economically feasible to adopt the integration of different technologies. In general, without adopting procurement policies, technology integration leads to increased costs. The EOQ policy enables greater cost savings by automating various procedures via smart contracts. In addition, the shared platform between actors allows them to take prompt actions and make more accurate predictions. In the to-be scenario, the EOQ policy allows a cost reduction from 57% to 79% for retailers. This advantage is absent for scenarios in which L4L or POQ is applied. These two procurement policies have no predictive advantage and therefore adopting this technology infrastructure only leads to increased costs. The robustness of these simulation models is also based on their sensitivity to different supply policies.

The last evaluation concerns the cost analysis of non-compliant product management. In the as-is scenario, monitoring and visibility are limited, which can lead to increase in costs and time. The results of the simulation models show that the EOQ policy for to-be scenario reduces costs for the three retailers by 45%, 53% and 61% respectively. Table V.22 summarizes the results of the cost analysis. It emerges that implementing these technologies is economically convenient mainly for the order management and the non-compliant products management for all procurement policies. For the logistics area, it is not economically convenient. For warehouse and the entire supply chain costs, the results are sensitive to the procurement policies considered. The EOQ policy is the most cost-effective when implementing these technologies. Compared to the L4L policy, there are double pluses in the area of non-compliant product management. Adopting the POQ policy is not economically convenient. Specifically, this procurement policy does not consider the advantages of smart contract automation.

Table V.22. *Summary of the cost analysis model (+ costs reduction, + + costs reduction more than 50%, - costs increase, - - costs increase more than 50%, ○ cost variations that range from -1% to +1%)*

Actors	**Order management**		**Logistics**		**Warehouse**		**Supply Chain**		**Non-compliant products**	
	1st year	**5th year**	**1st year**	**5th year**	**1st year**	**5th year**	**1st year**	**5th year**	**1st year**	**5th year**
EOQ policy										
Dairy farm	+	+	-	-	○	○	○	○		
3PL	+	+	-	-			-	-		
Wholesaler	+	+	○	○	-	-	-	-		
RA	+	+			-	+ +	-	+ +	+	+
RB	+	+			+	+ +	+	+ +	+ +	+ +
RC	+	+			+	+ +	+	+ +	+ +	+ +
Average evaluation	+	+	-	-	○	+	○	+	+ +	+ +
L4L policy										
Dairy farm	+	+	-	-	○	○	○	○		
3PL	+	+	-	-			-	-		
Wholesaler	+	+	○	○	-	-	-	○		
RA	+	+			+	+	+	+	- -	+
RB	+	+			- -	+	- -	+	+	+
RC	+	+			+ +	+	+ +	+	+	+
Average evaluation	+	+	-	-	–	+	–	+	+	+
POQ policy										
Dairy farm	+	+	-	-	○	○	○	○		
3PL	+	+	-	-			-	-		
Wholesaler	+	+	○	○	-	-	-	-		
RA	+	+			+	+	+	+	- -	+
RB	+	+			+	-	+	-	+	+
RC	+	+			+	-	+	-	+	+
Average evaluation	+	+	-	-	○	○	-	○	+	+

V.6. Future research and limitations

The chapter clarifies the economic feasibility of integrating technologies within the supply chain, for each actor and department. Several scientific contributions have pointed out that the integration of these technologies within supply chains requires high implementation costs without demonstrating this quantitatively. This research demonstrates the economic impacts that the combination of these technologies can bring in supply chains by also considering different procurement policies.

The limitations of this study depend mainly on the simulation models. First, it was not possible to simulate all the activities present for each actor, however, a precise product was identified that is exchanged between six actors in the chain. Furthermore, the simulation focuses on cheese wheels exported to France and does not consider the shipment of other products and actors. The input data are collected from scientific contributions and online reports and not from a real case study.

Future research could analyse in detail the costs for single actors or for each department. Finally, it would be interesting to evaluate the costs of other case studies in different areas and sectors to assess their economic feasibility.

General discussions and conclusions

In this final chapter, the main findings and theoretical implications of this thesis are discussed. Then, the managerial implications, the limitations and future research are outlined.

Main findings and theoretical implications

The general purpose of this thesis was to understand what impacts BT could carry out on supply chains and what factors hinder or promote its implementation. The research objectives that constitute the general objective of the thesis are:

- RO1: Identifying the factors that influence the use of BT for SCM;
- RO2: Identifying the factors that promote BT for enabling sustainable emerging practices;
- RO3: Identifying which technologies are most complementary with BT to achieve specific impacts;
- RO4: Identifying the impacts that the combination of different technologies such as blockchain, smart contracts, IoT and RFID could have on the order management;
- RO5: Identifying impacts that the combination of different technologies and the VMI strategy could have on supply chains with different players and in different areas for SCM;

- RO6: Identifying the implementation costs that the integration of different technologies can affect the supply chains.

In *Chapter I*, an SLR on blockchain features clarified what are the benefits, challenges and future research of this technology, both from a technological point of view and for operations in supply chains management. Most of the articles discuss the use of blockchains to trace entire processes and products in the supply chain and guarantee the so-called *trust*. The main technological advantages are related to the high security based on advanced encryption schemes. The main challenges to be faced are the technological ones for the proper use in SCM. Managing a high number of transactions could pose issues for current supply chains that handle high amounts of data. Moreover, the implementation costs of this technology are unclear. The low competence and managerial skills slow down their adoption on a large scale. There are many directions for future research. First, the use of blockchain in combination with other technologies should be investigated, and what could be the scenarios for the operations management. It would be appropriate to identify new business models that adopt emerging practices to carry out certain activities and improve operations efficiency. The first part of this chapter laid the foundation for a complete and comprehensive understanding of BT for SCM. The SLR provided the strengths and weaknesses of the technology within the supply chains. Certainly, features such as security, decentralisation and disintermediation are among the most important and fascinating as they reduce transaction costs and time, moreover, they shift the concept of trust and reliability in technology. However, efforts to improve technological performance from both an energy consumption and computational point of view are high. Private blockchains adopted in SCM can partly solve these problems. In this case, full transparency and visibility is not guaranteed as in public blockchains. On the one hand, this means avoiding opportunistic behaviour of actors in the supply chain; on the other hand, this solution produces less adoption of technology because certain activities can be carried out without this technology. Finally, this chapter outlines the potential future research of technology for SCM. Various themes will be analysed and studied in the following chapters such as the issue of sustainability, the integration of various technologies, the impact of blockchain on different areas of SCM and on supply chain members, and an overall cost-benefits evaluation. To date, the study of blockchain is still in its infancy, there are few cases where the technology is applied, and it is often simply mentioned and applied for marketing purposes. Further studies are needed to identify which activities can be covered by the application of blockchain and how it can bring value to companies. Several academic and governmental debates are needed on where and how blockchain should be used and how far transactions recorded in the distributed ledger are legal.

Hence, the contribution of this chapter is based on in-depth detailed analysis of **the key factors that influence the use of BT in SCM**. The factors that favour its use in companies are oriented toward considering blockchain as an anti-counterfeiting tool. Indeed, BT improves tracking and tracing aspects of product's life cycle activities and could enable a collaborative marketplace by leveraging P2P principles. Instead, the factors that slow down its use mainly depend on the low number of successful cases and the lack of knowledge of firms about the potential use of the technology. High implementation and conversion costs of IT systems hinder the adoption of small and medium-sized enterprises that do not recognize short-term economic benefits. Companies are sceptical of using the technology both because of the lack of regulations and standards and because of interoperability among the various IT systems already adopted. The research potential on BT for SCM is huge as highlighted in the chapter. In fact, a further contribution of this chapter is to give a research agenda on the advancement of BT theoretical research in the SCM. This chapter has highlighted the importance of investigating real case studies with interviews and surveys. It is important to understand the readiness of companies for adopting BT in SCM, evaluating success and failure business cases in the current scenario. It is clear that further theoretical insights into technological performance are crucial to adopt the technology without reducing the technological performance of already implemented IT systems.

The same chapter presents a review of sustainable emerging practices using BT. One example is the traceability of waste or carbon emissions on the blockchain. Blockchain can enable virtuous processes of social sustainability by tracing the working hours in developing countries. Of course, there are also unsustainable aspects such as the high energy consumption of public blockchains and the high investment costs for the infrastructure. Moreover, there could be opportunistic behaviour and privacy concerns if these transactions are not well monitored. This SLR identified several sustainable emerging practices that blockchain can enable. One of the main limitations of public blockchain is its high energy consumption. Therefore, these several sustainable blockchain-based practices may no longer be so if public blockchains are adopted. As stated above, the real and concrete value of blockchain is difficult to measure. How much does the adoption of sustainable practices using blockchain weigh against its energy consumption? Again, adopting private, consortium-based blockchains might not be cost-effective as existing IT systems could be implemented. It is still difficult to empirically establish which aspects prevail for the technology implementation. The research is expected to study in various directions, including the integrated use of different technologies such as sensors, IoT, artificial intelligence, drones together with blockchain platforms. Due to the limited real case studies, it is useful to develop simulation models able to predict the potential dynamics of technology in traditional supply chains. In this way, academics, researchers and practitioners will be able to understand the usefulness of the technology in various fields, sectors and activities. Key performance indicators will make it easier to analyse the cost-benefits of the technology. Consequently, it would be necessary to investigate several case studies and understand the new scenarios developed using qualitative and quantitative interviews.

The contribution of this second part of *Chapter I* is to give a different overview on the **factors that promote BT for enabling sustainable emerging practices**. In literature, BT is often considered a non-green technology because of its high energy consumption for validating nodes in public blockchains. Literature on SCM is increasingly pushing companies to adopt BT because it enables new sustainable practices for operations management. Of course, the use of private or consortium blockchain and its consensus mechanism enables the immutable recording of important information for the proper management of business practices. The recording of the transactions must be done without opportunistic behaviour of stakeholders. This chapter contributes to the literature by clarifying the various ways in which BT can be employed to support sustainability principles and identifying the key factors that promote BT for sustainable supply chains. Nevertheless, the chapter raises several doubts and concerns for its effective use in firms. In particular, it is unclear whether the technology enables more sustainable than unsustainable aspects and whether its implementation is really necessary considering current IT systems. Surprisingly, this analysis revealed that the adoption of BT can enable new sustainable practices such as reducing carbon emissions, improving waste management, circular economy, collaboration among participants and tracking of the products. Furthermore, the analysis identified less explored fields that are the social factors that can influence the use of technology such as ensuring human rights, fair practices at work and providing health and safety workplace.

In *Chapter II*, **the main combinations of blockchain with other technologies in SCM were investigated**. In particular, the main business processes were defined in which different technologies are most integrated with blockchain to achieve a specific impact. The analysis considered 9 technologies including: artificial intelligence, computing, digital applications, geospatial technologies, immersive environments, IoT, open and crowd-based platforms, proximity technologies and robotics. Blockchain is mainly integrated with the IoT and proximity technologies in which RFID and smart sensors are present. The integration of these technologies has a greater impact on internal aspects such as: supply chain relationship, cost reduction, time reduction and information management. The chapter offers a framework to support researchers and practitioners in addressing the challenges that will reshape supply chain processes with blockchain and its integration with other cutting-edge technologies. This chapter offers several analyses for reflection. First, the technology was born to work stand-alone for the exchange of cryptocurrencies. In order to effectively adopt blockchain within supply chains, following Industry 4.0 concepts, it needs to be integrated with other technologies. The SLR reveals this interesting insight. Technology needs data and transactions from external tools to be useful to supply chain members. Proximity technologies and IoT are key technologies to enable blockchain implementation. Starting from their weaknesses such as low security for data recording, blockchain strengthens and secures the entire technological infrastructure. However, other technologies contribute to broadening its domain of application. For instance, computing can be used as a supporting technology for data storage to reduce the scalability, throughput and storage problems that occur with blockchain. Finally, artificial intelligence can be widely used, especially if the data stored in blockchain are secure, certified and authenticated. The use of machine learning techniques on this data could lead to new knowledge and predictions. Beyond this perspective, this chapter opens up the horizons on which areas and impacts the combination of technologies could be applied in SCM and where no contributions have been found. This fourth dimension opens the mind to the potential of this technology in the supply chain landscape. In order to quantitatively assess these possibilities, simulations integrating several technologies have been considered in the following chapters.

In *Chapter III*, a simulation study comparing two scenarios, one as-is and one with blockchain, RFID, and IoT clarified what the time performance benefits are for handling orders among three actors. This chapter highlights **the potential impacts of integrating different technologies into supply chain operations with a focus on order management**. The integration of various technologies considerably reduces the number of manual operations. The low standardization of order entry systems can lead to data management issues. Data duplication explains why an order spends a lot of time in the system. In the as-is scenario, the quality control activities of the shipments are carried out only at delivery time of the goods and cannot be tracked. This generates an increase in the average times for non-compliant product management. The introduction of BT guarantees a single communication channel among the three players starting from the order generation by the retailer. IoT and RFID allow greater control and alignment between the real and virtual warehouse. The to-be scenario allows saving 3.2% on non-compliant product management thanks to the automation of smart contracts. For these specific events, 81 minutes on average were saved while 72 minutes on average were saved for each perfect order. In the second scenario, technologies control the entire system and guarantee the decision-making process more efficient. This chapter addresses the issues analysed previously from a theoretical point of view in a more practical and quantitative way. It is a preliminary simulation study on a few actors and only one area of SCM, i.e. order management. Indeed, the study arrives at results that are in line with the current literature. For example, time reduction and increased efficiency and productivity are proven. However, these benefits are not drastically high for operations management. Obviously, this study does not consider the advantage of using blockchain considering the security, traceability and privacy that are completely absent in the traditional scenario. This analysis reveals the advantages and disadvantages of each actor in both scenarios. For instance, in the to-be scenario, actors share a common platform for information exchanges, have full visibility and transparency of transactions, and control products and information exchanged in real time. Of course, the hypothetical costs of implementing this technological infrastructure and the lack of expertness in managing these technologies might discourage their adoption.

In *Chapter IV*, a simulation study comparing three scenarios, a traditional one, one with blockchain, RFID and IoT and a further one integrating the VMI strategy, clarified what are **the impacts in terms of time performance among different actors in different areas of SCM**. The time advantage of the scenario with blockchain, RFID and IoT is reduced because the procurement analysis process is optimized by the presence of inventory tracking systems in real time. The order management unit has better visibility of the inventory in its physical warehouse by consulting the distributed ledger. BT and smart contracts facilitate traceability systems, visibility of the entire supply chain and allow greater trust and collaboration between partners. The time reduction for lead time order preparation is between 10% and 13% among the three scenarios. The solution with VMI does not significantly reduce procurement times. The contribution of the VMI strategy is to mainly satisfy customers by reducing unfilled orders. As confirmed by the sensitivity analysis, by varying the percentage of product purchased, the scenarios with emerging technologies and the VMI strategy are more reactive to meet demand and make the supply chain resilient. For the traditional scenario, relations among organizations are carried out by nearby actors and planning takes place only on the historical purchase data that each actor receives from their downstream. Within the scenario with emerging technologies and especially the use of the VMI strategy, the forecasts are more accurate since the data is updated daily on the blockchain and shared among all the players. This implies that emerging technologies allow time reduction on some activities. The adoption of the VMI strategy, enabled by these tools, mainly strengthens the parameter of customer satisfaction by reducing unfilled orders. In this case, the benefits of the second and third scenarios concern the information exchange shared on a single platform. In this way, there is greater traceability of orders and visibility for participants. Using a single platform for the transactions exchange, the order receipt and order processing takes place in a shared and common platform. In the second and third scenarios, RFID, IoT and the blockchain are implemented within the physical warehouse of the dairy farm, wholesaler and during the shipment. Therefore, this system architecture allows for real-time stock-level data acquisition via RFID sensors, transferring data to the blockchain using the IoT infrastructure and recording it permanently and securely within the blockchain. The third scenario solves the communication problems among the actors and reduces the workload of the actors downstream of the dairy farm, guaranteeing greater flexibility in satisfying the final consumers. This chapter dissects and addresses in depth the issues announced in *Chapter III*. In this case, the presence of different actors and areas of SCM further clarifies the benefits of adopting these technologies. The use of the VMI strategy, enabled by blockchain, improves overall supply chain performance. Compared to the simulation in the previous chapter, the performance on the issue of unfilled orders makes the simulation more truthful and real. Again, this study does not consider the benefits of using blockchain for security, traceability and privacy that are completely absent in the traditional scenario. Further simulation models are needed to understand what other micro activities within the areas of order management, logistics and warehousing might be affected by using BT. Moreover, it would be interesting to assess through other simulation models what impacts the use of blockchain might have on supply chain relationships and time performance in other sectors such as high-tech, automotive, pharmaceutical or manufacturing.

In *Chapter V*, **a cost analysis** that compares two scenarios, one as-is and one with blockchain, RFID and IoT, **clarified what the implementation costs are for the various players and in which area of SCM**. The cost analysis, through the TDABC methodology, highlights how the integration of BT with other cutting-edge technologies within the supply chains leads to a general increase in costs. However, there is not an increase in costs for all areas of SCM. For example, for the order management unit it is possible to automate the activities of receiving, processing and generating orders. By reducing the time of these activities, costs are consequently reduced. The logistics and warehouse management areas have a higher cost due to the scenario in which emerging technologies are present. However, the cost variation of these two scenarios is not dramatically high. The investment in blockchain, IoT and RFID can be considered worthy as there are several process optimizations and there is greater transparency and visibility. The integration of these technologies guarantees to achieve other objectives in SCM. Considering the key features of BT such as decentralization and cryptography, the system guarantees a high level of cybersecurity. Compared to a centralized system vulnerable to hacker attacks and easy to tamper with, the network is decentralized, this creates an information redundancy system that guarantees greater security. The to-be scenario allows the tracking and monitoring of the truck journey and is highly secure as authorized network participants ensure that the truck can only be accepted by its real receiver, helping to reduce issues during contractual agreements. In this system, the certification process is fundamental. In the future, automation can help reduce errors, speed up tasks and reduce costs. This supply chain setup could become a successful solution for supply chain information communication channels by providing product lifecycle monitoring. The higher costs for the to-be scenario are offset by the integration of this set of technologies. The chapter highlights what procurement policies are economically convenient to adopt with this set of technologies. In particular, the EOQ policy guarantees cost reduction and improves sales forecasts by reducing unfilled orders. Sharing information enables decisions to be made in order to consistently meet downstream demand. The scenarios with L4L and POQ do not provide a predictive advantage and therefore using these procurement policies in the scenario to-be is not cost-effective. Finally, the chapter verified the impact that non-compliant product management has on supply chain costs. The EOQ procurement policy allows cost reduction for the three retailers of 45%, 56% and 63% respectively. The results show that blockchain is a valuable tool to overcome the collaboration issues in a supply chain and to minimize errors due to information asymmetry at the supply chain level. The contribution of this chapter is to provide a comprehensive overview of the economic organisational impact that blockchain has within supply chains. On the one hand it is shown how organisational processes within supply chains are reorganised using technology integration, and on the other hand an economic assessment of the feasibility of implementing these technologies within a supply chain is presented. The literature has superficially described the economic feasibility of these potential implementations within supply chains. The scenario provided evaluates supply chain members, different areas of the supply chains and furthermore the study is sensitive to different procurement policies. The results are in line with both the previous chapters of this thesis and the academic literature. The further contribution of this work is to offer a suggestion of when, where and how this solution should be implemented in supply chains. It is evident that procurement policies such as L4L and POQ are hardly suitable for improving operations management using this presented technological infrastructure. The following Table 1 proposes and summarises the results of each research objective.

Table 1. *Summary of findings for each research objective.*

No.	Research objectives	Findings
1.	Which are the main factors that influence the use of BT for SCM?	The key factors that favour its use in companies are oriented toward considering blockchain as an anti-counterfeiting tool because it improves tracking and tracing aspects

		of product's life cycle activities and could enable a collaborative marketplace by leveraging P2P principles. Instead, the key factors that slow down its use depend on the low number of successful cases and the lack of knowledge of firms about the potential use of the technology. In addition, high implementation and conversion costs of IT systems hinder the adoption of small and medium-sized enterprises that do not recognize short-term economic benefits.
2.	Which are the main factors that that promote BT for enabling sustainable emerging practices?	The adoption of BT can promote new sustainable practices such as reducing carbon emissions, improving waste management, circular economy, collaboration among participants and products tracking. Furthermore, BT could influence the social factors such as ensuring human rights, fair practices at work and providing health and safety workplace.
3.	Which are the technologies most complementary with BT to achieve specific impacts?	BT is mainly integrated with the IoT and proximity technologies in which RFID and smart sensors are present. The integration of these technologies has a greater impact on internal aspects such as: supply chain relationship, cost reduction, time reduction and information management.
4.	Which are the impacts that the combination of blockchain, smart contracts, IoT and RFID could have on the order management?	The introduction of BT on order management guarantees a single communication channel among the three players starting from the order generation by the retailer. IoT and RFID allow greater control and alignment between the real and virtual warehouse. The to-be scenario allows saving 3.2% on non-compliant product management thanks to the automation of smart contracts. Specifically, 81 minutes on average

		were saved for each event, while 72 minutes on average were saved for each perfect order.
5.	Which are the impacts that the same technologies and the VMI strategy could have on supply chains with different players and different areas for SCM?	The time advantage of the scenario with blockchain, RFID and IoT is reduced because the procurement analysis process is optimized by the presence of inventory tracking systems in real time. The order management unit has better visibility of the inventory in its physical warehouse by consulting the distributed ledger. Specifically, the time reduction for lead time order preparation is between 10% and 13% among the three scenarios. The contribution of the VMI strategy is to mainly satisfy customers by reducing unfilled orders.
6.	Which are the implementation costs that the integration of different technologies could affect the supply chains?	The cost analysis, through the TDABC methodology, highlights how the integration of BT with other cutting-edge technologies within the supply chains leads to a general increase in costs. However, there is not an increase in costs for all areas of SCM. For example, for the order management unit it is possible to automate the activities of receiving, processing and generating orders. By reducing the time of these activities, costs are consequently reduced. The logistics and warehouse management areas have a higher cost due to the scenario in which emerging technologies are present. The EOQ procurement policy allows cost reduction for the three retailers on average of 54%.

Table 2 shows a summary of the topics covered in this thesis.

Table 2. *Blockchain topics for each chapter.*

Topic	**Ch. I**	**Ch. II**	**Ch. III**	**Ch. IV**	**Ch. V**
BT features	✓				
Sustainable operations with BT	✓		✓		
BT integration with other technologies		✓	✓	✓	✓
Operational performance with BT			✓	✓	✓
Implementation Cost					✓

Starting from the general objective of this thesis, i.e. to understand what impacts BT has on SCM and what factors hinder or promote its implementation, the various chapters have shown with different perspectives the potential and criticalities of this technology for SCM.

Managerial implications

Managers and practitioners face many challenges to be able to deploy BT in supply chains. This section discusses research findings of practical implications for SCM wishing to implement the technology in their business.

The *first recommendation* relates to the overall assessment of blockchain features related to benefits, challenges and future research. BT offers several benefits of both IT security and information sharing. BT, being a distributed ledger, needs data from external tools that allow making appropriate decisions based on secure data in order to properly operate. Therefore, the adoption of other technologies that complement the use of blockchain is necessary. In literature, it is claimed that blockchain improves the automation of supply chain operations management and reduces the time for operations. In *Chapters III* and *IV*, it is shown an improvement in time performance for the lead time, the lead time for order preparation and the non-compliant product management. These improvements are based on several factors such as: the integration of various technologies, the data exchange on a single common platform and the use of smart contracts. In the absence of these conditions, BT alone may not achieve such performances.

The *second recommendation* regards the use of blockchain to promote emerging practices in sustainable supply chain operations. This chapter enriches the knowledge for managers and practitioners to improve their company's reputation by adopting sustainable practices with emerging technologies. However, *Chapter I* clarifies the presence of unsustainable IT aspects that need to be addressed. Adopting public blockchain for companies is not recommended due the high energy consumption. Before implementing the technology, careful evaluations must be made. In particular, it is necessary to assess whether the technology is useful for sustainable operations management or for purely marketing purposes. In addition, the current benefit that BT can bring within sustainable supply chains is still unclear as there are few real cases that have adopted these emerging sustainable practices.

The *third recommendation* concerns the implementation costs of blockchain within the supply chain. To achieve a certain degree of automation and cost reduction, it is necessary to adopt different technologies for SCM in order to reduce human errors and information asymmetry. The implementation of these technologies involves an increase in costs for the network players in various areas of the supply chain. The order management unit would benefit in terms of costs and time. Integrating this set of technologies for logistics and warehouse area leads to an overall increase in costs. Therefore, integrating them within a supply chain depends on several factors such as: the number of products managed, the different procurement policies and the actors considered.

The *fourth recommendation* concerns the specific case of cheese supply chain selected as a research context in this thesis. The study conducted in *Chapters III, IV* and *V* considers only one food product of Made in Italy excellence. The choice is based primarily on the importance of the traceability of this product. Finally, simulations on the supply chain for a modular product could further reduce the time needed to exchange information and improve the overall performance.

The *fifth recommendation* relates to the organisational change that BT, interconnected with other technologies, brings to companies. Considering its positive features, it is necessary to understand whether the implementation of BT can bring more value to the company. For instance, tracking and tracing could be carried out by existing IT systems, yet presenting a greater risk to IT security. Big companies with a high number of transactions and activities to monitor, might consider BT useful to keep immutable track of the several events. Specifically, traditional sectors such as agri-food, luxury, and high-fashion supply chains could leverage the rise of this technology to improve their brand reputation by ensuring sustainable processes and products, enabling fair practices, and finally being transparent with customers. However, it should be considered that BT projects such as Tradelens, where IBM collaborated with Maersk, did not meet positive expectations (Maersk, 2022). BT works when the parties involved are on the same level of importance following P2P principles. In fact, if only one actor in the SC manages the platform, the advantages are only relative to the master node. Therefore, small and medium size enterprises that adopt technology to follow the guidelines of the supply chain leader have difficulty managing the new IT systems and any additional implementation costs. Moreover, small companies are dubious to adopt these technologies due to their limited skills, resources, and technological infrastructure.

The *last recommendation* is to consider the various open issues related to technology such as: scalability, throughput, storage, transaction speed that could adversely affect business performance if not properly managed. In addition, a conversion of managerial skills is necessary. Introducing these technologies within small and medium-sized enterprises could make operations management more difficult. In particular, the initial investment in the supply chains is significant, it is necessary to understand the purpose of implementing these technologies and how they can be fully exploited after implementation.

Limitations and future research

This thesis provides in-depth analysis on how BT can be a promising technology for changing supply chain organizational models. It indicates several future research directions.

In *Chapter I*, several insights for future research were shown based on the technological performance of blockchain in supply chains. Some research ideas have been further explored in the following chapters. For example, the issues of sustainability and the integration of the various technologies were explored in *Chapters II* and *III*. Through simulations, it was possible to quantify *ex-ante* the degree of automation of the various technologies and the benefits on the operations management in *Chapters IV* and *V*. Finally, a cost analysis was conducted to better understand how much it is economically convenient to implement different technologies in a supply chain in *Chapter V*.

From the analysis, it emerged that ideas for future research could investigate the feasibility of the different simulation scenarios. This type of approach could be applied to a network in which there are several actors. In addition, other procurement strategies beyond VMI, such as Just in Time, could be considered in order to assess their procurement performance. It would be interesting to identify simulating sustainable supply chain operations and assess their environmental, economic and social benefits. The issue of resilient supply chains is assuming greater importance, especially after the disaster of the Covid-19 pandemic. It is necessary to investigate how BT could improve operations management in cases of disruption events and how they can be mitigated by the presence of other technologies.

As highlighted in *Chapter I*, research on blockchain technologies could be extended to further areas such as: security and privacy, smart contract development, the creation of new business models, the study of business case studies. It would be useful to investigate who should check the records registered in the blockchain and how often? Who are the actors responsible for managing blockchain in a supply chain? What are the activities that could be automated through smart contracts as well as for traceability and automation processes? Could BT develop new business models by creating new sales channels? To date, what are the enabling factors and the barriers that BT faces in small and medium-sized enterprises?

It is important to define how blockchain could be a competitive technology in the current IT scenario. Future studies should focus on computational costs, transaction processing speed, data storage capacity, and overall efficiency of value chains. Another hot topic is to evaluate the alignment of government guidelines with the practical application of BT. Governments and industries should jointly recognize the solutions where interoperability could be achieved. Governments should encourage the digitization of public administration and the introduction of technologies such as blockchain. Further research directions include in-depth study of issues such as collaboration on business operations thanks to information sharing through the blockchain platform. It would be helpful to understand how to permanently remove middlemen along the supply chain and what the cost savings are. Further investigation in real cases is needed to understand the real benefits of blockchain. Above all, when considering blockchain as a paradigm that opens up collaboration between companies, it is important to understand how the technology can enable such collaboration between supply chain members.

The thesis has some limitations. First, the research in *Chapters I* and *II* is based on a SLR. Some benefits, challenges and future research may not have been considered as they may be present in other journals outside the research sample. Moreover, not all emerging blockchain-based practices can be counted, and some may still be tested. Secondly, in *Chapters III* and *IV* the use of simulation models made it possible to measure *ex-ante* the impacts that BT connected to other technologies has on the supply chain. However, relying on single case studies may not guarantee generalizability of the results in other sectors with other configurations and procurement policies. Therefore, the analysis is limited to the actors considered. *Chapter V* presents a cost analysis considering the integration of various technologies in a cheese supply chain. Indeed, various activities and operations may not have been considered and accounted for in the cost model. Given the difficulty of fully representing the real world, it was decided to introduce some limitations for the activities carried out by the actors. For example, the cost of the technological infrastructure of the to-be scenario was allocated only to cheese exported abroad. It would be necessary to evaluate through surveys and interviews with companies that have implemented the technology and highlight the real disadvantages and advantages. Field research is necessary to investigate issues that are not present in the current academic literature.

Final word

In this thesis, various aspects of BT were explored to enrich the comprehension of how to manage the technology and implement it successfully. The research used different methodological approaches (literature review, simulation models, cost allocation via TDABC method) to capture the various aspects of the technology for SCM. The results of the chapters have provided valuable insights that can be used to evaluate BT within supply chains.

This research was motivated by the emergence of employing this technology in supply chain and its promising use in logistics and SCM. I hope that the advanced intuitions presented in this thesis can help the different stakeholders to implement BT with greater diffusion and enable sustainable and integrated emerging practices for achieving the concept of Industry 5.0.

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Appendix A

Table A. *Results from discrete event simulation of non-compliant products parameters.*

	Scenario AS - IS			Scenario TO - BE		
EOQ 1 year	RA	RB	RC	RA	RB	RC
Number of unfilled orders	0	1	1	0	0	0
Number of non-compliant products	4	2	3	3	2	3
Non-compliant products management time (h)	69	81	85	27	29	34
EOQ 5 years						
Number of unfilled orders	10	20	16	4	5	3
Number of non-compliant products	17	15	18	15	16	15
Non-compliant products management time (h)	75	80	82	33	31	34
L4L 1 year						
Number of unfilled orders	1	0	1	1	0	0
Number of non-compliant products	3	4	4	3	3	4
Non-compliant products management time (h)	24	23	22	16	20	19
L4L 5 years						
Number of unfilled orders	14	14	14	13	14	12
Number of non-compliant products	16	18	17	16	16	17
Non-compliant products management time (h)	27	23	22	20	20	19
POQ 1 year						
Number of unfilled orders	0	0	0	0	0	0
Number of non-compliant products	3	3	3	3	3	3
Non-compliant products management time (h)	58	65	65	40	44	34
POQ 5 years						
Number of unfilled orders	24	22	21	23	22	22
Number of non-compliant products	17	17	17	15	17	16
Non-compliant products management time (h)	79	77	76	62	65	61